

***THE EFFECTS OF MACROBENTHOS ON
SEDIMENT-WATER OXYGEN AND AMMONIUM
FLUXES***

Final Report

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PREFACE

This report is submitted in accordance with the Schedules of Deliverables set out in US Army Corps of Engineers Contract between the Corps and the University of Maryland's Center for Environmental and Estuarine Studies, Chesapeake Biological Laboratory.

This report contains a description of study goals, laboratory and analytical procedures and a description of results. A complete hard copy of the data is also included. The entire report and all data are also available in electronic format and can be requested from W. R. Boynton, Chesapeake Biological Laboratory, Box 38, Solomons, MD 20688 (tel: 1-410-326-7275; e-mail boynton@cbl.cees.edu). The Data Dictionary referred to in this report is also available from the same source.

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INTRODUCTION

The sediments of Chesapeake Bay and other shallow estuarine ecosystems are an important location in determining the fate of nutrients entering the estuary and a sink for dissolved oxygen. In a simplified fashion, a large fraction of the inorganic nutrients that enter the bay from various sources are utilized by phytoplankton and converted to particulate organic forms of nitrogen and phosphorus (Boynton et al. 1995). Some of this material is grazed by zooplankton and other water column filter feeders with subsequent deposition to sediments of fecal pellets and other particulate wastes. Another portion is rapidly metabolized to inorganic end products in the water column by bacteria and other small heterotrophs with little deposition of particulates to bottom sediments. Finally, some particulate material is directly deposited to the sediments and this is a particularly large event following the spring and fall diatom blooms. At or near the sediment surface, this organic matter is either stored in the accreting sediment column in depositional areas of the bay or consumed by sediment microbes and benthic macroinvertebrates.

Both the decomposition of deposited organic matter and the excretions of macroinvertebrates release nutrients back to overlying waters. These "recycled" nutrients are in labile form (i.e. NH_4^+ and PO_4^-) readily available for uptake by phytoplankton. Boynton et al. (1995) estimated sediment recycling of nutrients can supply 55 to 230 % of nitrogen (N) and 45 to 215 % of phosphorus (P) demand by estuarine phytoplankton communities in some portions of the bay. Because of several vertical mixing processes which transport nutrients generated by sediments in near-bottom waters to euphotic waters, these nutrients can support continued or increased algal production. This algal production, based now on recycled nutrients from sediments, is again available for grazing and all of the pathways described above. Previous research and monitoring have indicated that sediments have an important impact on water quality in the Chesapeake Bay and other shallow estuarine systems.

Because of the strong impact sediments can have on water quality, the role of sediments in storing, transforming, and releasing nutrients and consuming dissolved oxygen has been incorporated into the Chesapeake Bay water quality model. Other steps are being taken to further the model's performance, and one of these involves incorporation of a simplified benthic food web.

Many conceptual and empirical problems arise relative to including a food web in the water quality model. One such problem is quantifying the role benthic macrofauna play in sediment oxygen consumption and nutrient release. It is the purpose of this study to estimate the portion of sediment oxygen consumption (SOC) and sediment ammonium (NH_4^+) release directly attributable to benthic invertebrates via the respiratory use of oxygen and catabolic release of ammonium.

APPROACHES, METHODS AND MATERIALS

Background Information

The Sediment Oxygen and Nutrient Exchanges (SONE) program has been a part of the Ecosystem Processes Component (EPC) of the Maryland Chesapeake Bay Water Quality Monitoring Program since July 1984 and a somewhat modified version of this program is presently active. The SONE program monitors the net exchange of oxygen and nutrients between sediments and overlying water. Since it appears that external nutrient and organic matter inputs (e.g. riverine, point and atmospheric) ultimately determine the magnitude of sediment processes, monitoring these processes serves as a good indicator of the effectiveness of strategies aimed at decreasing these loads and thereby improving bay water quality and habitat conditions. In addition to being an indicator of current conditions and trends, SONE results have been integrated with other parts of the Chesapeake Bay Program, such as the water quality model, where the goal is to provide predictions of the likely consequences of nutrient input reductions. As indicated previously, an explicit benthic macroinvertebrate component is being added to the bay water quality model to further refine model predictions and to include living resource components (i.e. SAV, benthic macroinvertebrates) which will be influenced by changes in bay water quality. In order to accomplish this addition to the model, data were needed which would provide estimates of benthic macroinvertebrate oxygen consumption rates and nitrogen excretion rates and comparisons of these rates to total rates of SOC and ammonium flux observed in Chesapeake Bay sediments during various periods of the year.

SONE Program Data and Methods

Data Availability: Intact sediment samples (triplicate samples) were collected at 8 SONE stations from August 1985 through November 1988 (Table 1 and Figure 1). Four stations were located in the mainstem of Chesapeake Bay (Still Pond [STPD], R 78, R64, Point No Point [PNPT]), two in the Patuxent River tributary (Buena Vista [BUVA] and Saint Leonards Creek [STLC]), and two in the Potomac River tributary (Maryland Point [MDPT] and Ragged Point [RGPT]). Most of these stations were sampled four times each year, once in spring and fall and twice during summer months (Table 2). A total of 251 cores were selected for examination from the total number of cores collected at the 8 stations over the four year period (768 cores).

Table 1. A listing of station names, station codes, locations, station depths and salinity characteristics at sites where benthic macroinvertebrates were collected from benthic cores.

<u>Region</u>	<u>Station Name</u>	<u>Station Code</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Station Depth</u>	<u>Salinity Code</u>
Chesapeake Mainstem	Still Pond	SLPD	39° 20.81'	76° 10.72'	10.4	Oligohaline
	Buoy R-78	R-78	38° 57.81'	76° 23.62'	15.8	Mesohaline
	Buoy R-64	R-64	38° 33.59'	76° 25.63'	16.8	Mesohaline
	Point No Point	PNPT	38° 07.99'	76° 15.13'	14.2	Mesohaline
Patuxent River	Buena Vista	BUVA	38° 31.12'	76° 39.82'	5.8	Oligohaline
	St. Leonard Creek	STLC	38° 22.88'	76° 30.06'	7.0	Mesohaline
Potomac River	Maryland Point	MDPT	38° 21.32'	77° 11.64'	10.2	Oligohaline
	Ragged Point	RGPT	38° 09.86'	76° 35.52'	16.5	Mesohaline

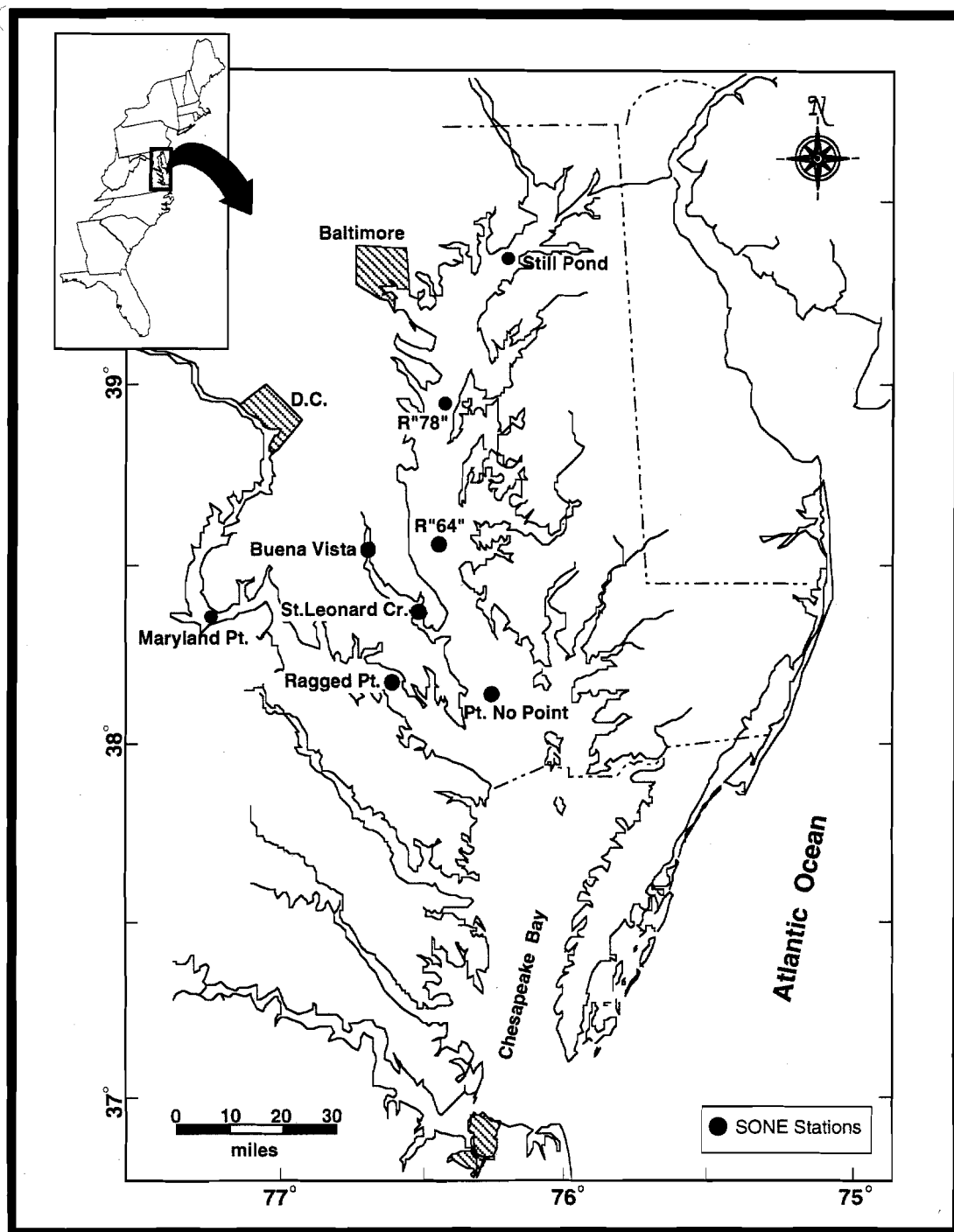


Figure 1. Map of Chesapeake Bay and tributary rivers showing approximate location of SONE sampling locations where intact sediment core samples were collected and benthic macroinvertebrates quantified. Samples were collected from 1985 through 1988. See Table 1 for exact station locations and other descriptions of these sites.

Table 2. A listing of station names, station codes, sampling dates and number of sediment box cores examined for macrofaunal numerical abundance and biomass. The locations of sampling stations are shown in Figure 1. A total of 251 sediment cores were examined.

<u>Station</u>	<u>Code</u>	<u>1985</u> <u>AUG</u>	<u>1985</u> <u>OCT</u>	<u>1986</u> <u>MAY</u>	<u>1986</u> <u>JUN</u>	<u>1986</u> <u>AUG</u>	<u>1986</u> <u>NOV</u>	<u>1987</u> <u>APR</u>	<u>1987</u> <u>JUN</u>	<u>1987</u> <u>AUG</u>	<u>1987</u> <u>NOV</u>	<u>1988</u> <u>APR</u>	<u>1988</u> <u>JUN</u>	<u>1988</u> <u>AUG</u>	<u>1988</u> <u>NOV</u>
Still Pond	STPD	3	3	3	3	3	3	2	3	3	3	3	2	3	3
R 78	R78	3	3	3	0	0	0	0	0	0	0	0	0	0	0
R 64	R64	3	3	0	3	3	3	3	3	2	3	3	3	3	0
Point No Point	PNPT	1	2	0	0	0	0	0	0	2	3	3	3	3	3
Buena Vista	BUVA	2	3	3	3	1	3	3	2	3	3	2	3	3	3
St. Leonard's Ck	STLC	3	2	3	3	3	3	3	3	3	3	3	3	3	2
Maryland Point	MDPT	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Ragged Point	RGPT	0	3	3	0	0	0	3	3	3	3	2	3	2	3
TOTALS		18	22	18	15	13	15	17	17	19	21	19	20	20	17

Detailed methods are described in the Ecosystem Processes Component (EPC) Study Plan (Garber et al., 1987) and the EPC Data Dictionary (Boynton and Rohland, 1990). Field and laboratory methods are summarized here to provide a general description of: (1) how estimates of total net sediment-water exchanges of oxygen and ammonium were obtained; (2) how benthic macroinvertebrate densities and biomass were determined; (3) how estimates of macroinvertebrate oxygen consumption and ammonium excretion rates were calculated

Sediment-Water Exchanges Intact sediment cores were obtained using a modified Bouma box corer. After deployment and retrieval of the box corer, the metal liner was replaced with a Plexiglass liner. The sediment core was visually inspected for disturbances. A satisfactory core was then placed in a darkened bottom water filled holding tank prior to further processing. A Plexiglass microcosm, identical to those containing bottom sediments, was filled with bottom water and used as a blank. The three cores and the blank were slowly flushed with fresh bottom water. The replacement of overlying water with fresh bottom water ensured that water quality conditions in the cores closely approximated *in-situ* conditions.

The cores were sealed with air-tight top and bottom plates and placed in a darkened water bath to maintain ambient temperature. Gentle circulation of water, with no induction of sediment resuspension, was maintained in the cores during the measurement period via the stirring devices attached to the oxygen probes. Oxygen concentrations and temperature were recorded and overlying water samples (35 ml) were extracted from each core and the blank every 60 minutes over a 4 hour incubation period. During the incubation period, five overlying water samples were extracted from each core. As a nutrient sample was extracted from a core, an equal amount of ambient bottom water was added to the core to prevent air bubbles from accumulating in the core. Water samples were filtered with a Gelman filter and immediately frozen for later analysis of ammonium (NH_4^+), and dissolved inorganic phosphorous (DIP or PO_4^{3-}) concentrations. Oxygen and nutrient fluxes were estimated by calculating the mean rate of change in concentration over the incubation period and converting the volumetric rate to a flux using the volume:area ratio of each core.

Bottom Water Column Characteristics: Measurements of temperature, salinity and dissolved oxygen were also taken approximately 0.5 meter from the sediment surface immediately after obtaining intact sediment cores for incubation. A submersible pump and a Hydrolab S-II Data Sonde CTD were used to obtain these measurements.

Benthic Macroinvertebrate Analyses

Sample Collection and Enumeration: After the incubation period, the sediments in each core were sieved using a 0.5 mm mesh sieve. Macroinvertebrates from each core were then gently rinsed into a container. Buffered 10% formalin with rose bengal was then added to each container. Containers were capped and stored. Samples were later sent to Cove Corporation (Lusby, Maryland) where organisms were identified and individuals counted to the level of species or species groups. Preserved wet weight of these organism groups was also recorded. Table 3 is a copy of the data sheets used by Cove Corporation. Picked samples were stored in 75% ethanol in small vials.

Estimation of Macroinvertebrate Respiration: No direct measurements of macroinvertebrate respiration are available for the stations sampled. However, since the macroinvertebrates recovered from each core were weighed and identified and the relationship between body size (weight) and respiration is reasonably well known, it was possible to calculate rates of macroinvertebrate respiration for each core. First a literature search was conducted to determine the relationship between body size (weight) and respiration for benthic organisms under temperature conditions similar to those observed in the bay. The relationship of interest is generally expressed as;

$$R = aW^b \text{ or } \log R = \log a + b \cdot \log W$$

where **R** is the respiration rate in units O_2 per individual per time period (i.e. $\mu l O_2$ /individual/hr) or the weight specific respiration rate in units O_2 per unit weight per time period (i.e. $\mu l O_2$ /mg of body wt./hr), **W** is the body weight of the organism, **b** is an exponential constant and **a** is a constant of proportionality.

In choosing reasonable algorithms to calculate macroinvertebrate respiration rates, a specific set of criteria were followed and these included consideration of the following four issues: (1) experimental measurements were taken at temperatures (15-28 C) similar to those found in the Chesapeake Bay at the time samples were collected (2) the weight range of individuals used in the study were similar to those in Chesapeake Bay; (3) the species studied were at least similar to the species found in Chesapeake Bay; (4) weight specific respiration rates for the species of interest were reported. Many, if not most, of the literature sources were rendered useless because they did not include weight specific respiration rates or because the organisms used were much larger than the ones found in this study. Two studies met all four criteria and these were used in making all estimates of benthic macroinvertebrate respiration rates. The first was a study by Ikeda (1970) and the second by Kennedy and Mihursky (1972). A summary of the most useful literature

Table 3. An example of data sheets used to encode species level abundance and biomass data collected from the SONE Program sediment cores. The number of individuals (#) and wet weight (g) refers to the number of individuals found in a single sediment core and the combined wet weight of these individuals.

SPECIES ABUNDANCE DATA SHEET							
STATION:							
SONE #:							
Collection Date:							
Replicate:							
Species	Group	#	Wet wt.(g)	Species	Group	#	Wet wt.(g)
Glycinde solitaria	Polychaeta			Balanus improvisus	Balanidae		
Heteromastus filiformis	Polychaeta			Chiridotea almyra	Isopoda		
Hobsonia florida	Polychaeta			Corophium lacustre	Amphipoda		
Hyperateone heteropoda	Polychaeta			Cyathura polita	Isopoda		
Laeonereis culveri	Polychaeta			Edutea triloba	Isopoda		
Leitoscoloplos sp.	Polychaeta			Gammarus daiberi	Amphipoda		
Marenzelleria viridis	Polychaeta			Lepidactylus dytiscus	Amphipoda		
Mediomastus ambiseta	Polychaeta			Leptocheirus plumulosus	Amphipoda		
Neanthes succinea	Polychaeta			Leucon americanus	Cumacea		
Oligochaeta	Oligochaeta			Melita nitida	Amphipoda		
Parahesione luteola	Polychaeta			Monoculodes sp. 1	Amphipoda		
Paraonis fulgens	Polychaeta			Mucrogammarus macronatus	Amphipoda		
Paraprionospio pinnata	Polychaeta			Neomysis americana	Mysidacea		
Pectinaria gouldii	Polychaeta			Rhithropanopeus harrisi	Decapoda		
Podarkeopsis levifuscina	Polychaeta			Edwardsia elegans	Anthoza		
Strablospio benedicti	Polychaeta			Stylochus ellipticus	Turbellaria		
Tharyx sp. A	Polychaeta			Carinoma tremaphorus	Nemertinea		
Acteocina canaliculata	Gastropoda			Micrura leidyi	Nemertinea		
Acteon punctostriatus	Gastropoda			Chironomidae	Chironomidae		
Gemma gemma	Bivalvia			Phoronis Sp.	Phoronida		
Littoridinops tenuipes	Gastropoda			Leptosynapta tenuis	Holothuroidea		
Macoma balthica	Bivalvia			Saccoglossus kowalevskii	Hemichordata		
Macoma mitchelli	Bivalvia			Sigambra tentaculata	Polychaeta		
Mulinia lateralis	Bivalvia			Pseudeurythoe paucibranchiata	Polychaeta		
Mya arenaria	Bivalvia			Nephtys sp (juv)	Polychaeta		
Mytilopsis leucophaeta	Bivalvia			Cratena pilata	Gastropoda		
Rangia cuneata	Bivalvia			Amphipora bioculatus	Nemertinea		
Tagolus plebeius	Bivalvia			Mysidopsis bigelowi (tail)	Polychaeta		
Leitoscoloplos robustus	Polychaeta			Diadamene leucolena	Anthozoa		
Parvilucina multilineata	Bivalvia			Cyclaspis varians	Cumacea		
Microphthalmus abervans	Polychaeta			Gammarus sp. (head only)	Amphipoda		
Polydora cornuta	Polychaeta			Lironeca ovalis	Isopoda		
Lyonsia hyalina	Bivalvia			Hydrobia truncata	Gastropoda		
Loimia medusa	Polychaeta			Haminoea solitaria	Gastropoda		
Rictoxis punctostriatus	Gastropoda			Bivalvia (ind.)	Bivalvia		
Asabellides oculata	Polychaeta			Hypereteone foliosa	Polychaeta		
Glycera dibranchiata	Polychaeta			Chaoborus sp.	Diptera		
Ampelisca abdita	Amphipoda			Naididae	Oligochaeta		
Ensis directus	Bivalvia			Boccardiella ligerica	Polychaeta		
Odostomia engonia	Gastropoda			Nemertinea(sp?)	Nemertinea		
Oxyurostylis smithi	Cumacea			Turbellaria sp. A (Acoela)	Turbellaria		
* = wt. of other polychaeta							
# = wt. of macoma sp. (ie Tellinidae)							

sources is provided in Table 4 and the specific algorithms used to calculate benthic macroinvertebrate respiration rates are provided in Tables 5a and 5b.

Before the algorithms provided by Ikeda (1970) and Kennedy and Mihursky (1972) could be used, macroinvertebrate data supplied by Cove Corporation were sorted, grouped and converted to useable units. First, species were sorted into taxonomic groupings. Group totals were calculated from the sum of individuals and preserved wet weights in each group. Preserved wet weights were converted to live wet weights by a factor of 1.1 (preserved wet weight \times 1.1 = live wet weight; Weisberg per comm). When needed, live wet weights were converted to dry weights using a factor of 0.2 (live wet \times 0.2 = dry weight; Weisberg per comm). Bivalve weight data from Cove Corporation included the weight of shells. Shell free weight was calculated using a factor of 0.47. This factor was obtained by directly measuring the weights of shells and tissues of a subsample of bivalves. The average ratio of bivalve tissue weight to whole bivalve (shell + tissue) weight was 0.47 (tissue preserved weight = 0.47 \times whole bivalve preserved weight).

Mean individual weights were calculated from the group total weight and total number of individuals (average weight/individual = group total weight/group total number of individuals). A weight specific respiration rate for each group was estimated using algorithms from Ikeda (1970) or Kennedy and Mihursky (1972; Tables 5a and 5b). The respiration rate was multiplied by the total weight of the group and divided by the area of the core (in units of m^2) to estimate group respiration in gO_2 per square meter per day ($\text{gO}_2 \text{ m}^{-2} \text{ day}^{-1}$). Biomass measurements from the cores were also converted to areal estimates by dividing the group total weight measured in each core by the area of the core (in units of m^2) and reported as shell free dry weight per square meter (gm^{-2}).

Estimation of Macroinvertebrate Ammonium Excretion Rates:

No direct measurements of macroinvertebrate excretion rates were available for the stations sampled. However, since the macroinvertebrates recovered from each core were weighed and identified and the relationship between body size (weight) and ammonium is reasonably well known, it was possible to calculate rates of macroinvertebrate ammonium excretion for each core. As in the case above for benthic macroinvertebrate respiration, a literature search was conducted to determine the relationship between body size (weight) and respiration for benthic organisms under temperature conditions similar to those observed in the bay. The relationship of interest is generally expressed as;

$$V = aW^b \text{ or } \log V = \log a + b \cdot \log W$$

where V is the ammonium excretion rate in units of nitrogen per individual per time period (i.e. $\text{mgN/individual/day}$) or the weight specific excretion rate in units N per unit weight

Table 4. A summary of literature sources consulted in selecting algorithms for estimating benthic macroinvertebrate respiration rates. The algorithms used in this work were found in the papers listed below in bold type.

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- Zeuthen, E. 1953. Oxygen uptake as related to body size in organisms. *Q. Rev. Biol.* 28(1):1-12.

Table 5a. The algorithms used to estimate benthic macrofaunal respiration rates for all non-bivalve species are provided below. The first two equations are from Ikeda (1970). For the purposes of this study three different temperatures ranges were selected and applied to the data set as appropriate. Temperature is in C, respiration rate has units of $\mu\text{O}_2/(\text{mg}\cdot\text{hr})$, weight (W) is in mg (live wet weight), n is number of individuals used to develop the algorithm and r is the correlation coefficient. All of the algorithms were significant at $p<0.01$. The third equation is from Kennedy and Mihursky (1972) and was used for non-bivalves when live wet weights per individual were greater than 10 mg (individuals of this size were not included in the Ikeda (1970) study).

Temperature	Algorithm	n	r	Organism Type
<14.5	$R=0.41013+-0.18702*\log W$	40	0.660	all non bivalves
14.5< and <22.5	$R=0.72074+-0.30237*\log W$	15	0.857	all non bivalves
>22.5	$R=5.9897+-5.9108*\log W$	48	0.532	large non-bivalves

Table 5b. The algorithms used to estimate benthic macrofaunal respiration rates for all bivalve species are provided below. The equations are from Kennedy and Mihursky (1972) and are based on *Macoma balthica* data. For the purposes of this study three different temperatures ranges were selected and applied to the data set as appropriate. Temperature is in C, respiration rate has units of $\mu\text{O}_2/(\text{mg}\cdot\text{hr})$, weight (W) is in mg (dry tissue weight).

Temperature	Algorithm	Organism Type
<15.0	$\log R=0.471+-0.742*\log W$	bivalves
15.0< and <25.0	$\log R=0.946+-0.878*\log W$	bivalves
>25.0	$\log R=1.214+-0.942*\log W$	bivalves

per time period (i.e. mgN/mg of body wt./day), **W** is the body weight of the organism, **b** is an exponential constant and **a** is a constant of proportionality.

In the process of selecting algorithms to calculate macroinvertebrate ammonium excretion rates, the same specific set of criteria were used as for selecting algorithms for calculating respiration rates: (1) experimental measurements were taken at temperatures (15-28 C) similar to those found in the Chesapeake Bay at the time samples were collected (2) the weight range of individuals used in the study were similar to those in Chesapeake Bay; (3) the species studied were at least similar to the species found in Chesapeake Bay; (4) weight specific respiration rates for the species of interest were reported. There do not appear to be nearly as many measurements of ammonium excretion available as is the case for respiration rate measurements. Of those we have reviewed, many, if not most, of the literature sources were rendered useless because they did not include weight specific excretion rates or because the organisms used were much larger than the ones found in this study. Only one study met all four criteria and the algorithm from this study was used in making all estimates of benthic macroinvertebrate ammonium excretion rates. This study was conducted by Shumway and Newell (1984). A summary of some literature sources is provided in Tables 6 and 7 and the specific algorithm used to calculate benthic macroinvertebrate ammonium excretion rates is provided in Table 6 (in bold face type).

Data Management

Data from Cove Corporation were entered into Microsoft Excel 5.0. Printouts of the data sheets were proofed and all errors corrected. A second printout was also proofed to verify corrections. Data were stored in Microsoft Excel 5.0 workbooks. The files are named according to Microsoft Excel conventions. Each station has a workbook of the same name, and each worksheet in the workbook contains data for one core and is named by the date of the sample and the replicate number of the core. Respiration and ammonium excretion rate data are also stored in Microsoft Excel 5.0 using the same naming conventions for station, date and core replicate.

Table 6. A summary of some nitrogen excretion rates of macrobenthic animals reported in the literature. The entry in bold type was selected as the algorithm used in generating all estimates of macrobenthic ammonium release. The excretion rate units shown in the table are the units of the rate V or Y, also shown in the first column of the table. The abbreviations DW, flesh, WW and AFDW represent dry weight, only flesh weighed (shell not included), wet weight and ash free dry weight, respectively.

Rate	Species	Species Wt.	Temp	Excretion Rate Units	Reference
$V=6.27W^{0.287}$	Mytilus	0.13 - 1.2 g	20°C	µgN/hr, g DW (flesh)	Bayne and Scullard 1977
$V=3.644W^{0.826}$	Mytilus	0.14 - 0.56 g	20°C	µgN/hr, g DW (flesh)	Bayne and Scullard 1977
$V=7.11W^{1.16}$	Mytilus	0.02 - 2.0 g	15°C	µgN/hr, g DW (flesh)	Bayne and Scullard 1977
$V=0.27W^{0.62}$	Nereis	0.4 - 4.8 g	16°C	µmolN/hr, g WW	Kristensen 1984
$\log(Y)=0.94*\log(X)+1.33$	Mercenaria	1 - 2 g	20°C	µmolN/day, g DW (flesh)	Srna and Baggaley 1976
$V=83W^{0.467}$	Loimia (polychaete)	69 - 372 mg	20°C	nmolN/hr, mg AFDW	Mayer (Thesis) 1992
$V=.86W^{1.08}$	Phronima (amphipod)	36 mg	13°C	µgN/individual/day, mg DW	Mayzaud and Dallot 1973
$V=.0015W^{0.541}$	Mulinia lateralis	0.1 - 10 mg	10°C	mgN*day ⁻¹ , mg DW (flesh)	Shumway and Newell 1984
$V=.0038W^{0.564}$	Mulinia lateralis	0.1 - 10 mg	20°C	mgN*day⁻¹, mg DW (flesh)	Shumway and Newell 1984
$V=.0245W^{0.622}$	Mulinia lateralis	0.1 - 10 mg	30°C	mgN*day ⁻¹ , mg DW (flesh)	Shumway and Newell 1984

Table 7. A summary of the literature sources consulted in selecting an algorithm for estimating ammonium excretion rates of benthic macroinvertebrate animals.

- Bayne, B.L. and C. Scullard. 1977. Rates of nitrogen excretion by species of *Mytilus* (bivalvia:mollusca). *J. Mar. Biol. Ass. U.K.* 57:355-369.
- Blackburn, T.H. and K. Henriksen. 1983. Nitrogen cycling in different types of sediments from Danish waters. *Limnol. Oceanogr.* 28(3):477-493.
- Kristensen, E. 1984. Effect of natural concentrations on nutrient exchange between a polychaete burrow in estuarine sediment and the overlying water. *J. Exp. Mar. Biol. Ecol.* 75:171-190.
- Mayer, M.S. *Effects of Benthic Macrofauna on Nitrogen Cycling and Oxygen Consumption of Estuarine Sediments*. Unpublished Doctor's dissertation, The University of Maryland, 1992.
- Mayzaud, P. and S. Dallot. 1973. Respiration et excretion azotee du zooplankton. I. Evaluation des niveaux metaboliques de quelques especes de Mediterranee occidentale. *Mar. Biol.* 19:307-314.
- Shumway, S.E. and R.C. Newell. 1984. Energy resource allocation in *Mulinia lateralis* (say), an opportunistic bivalve from shallow water sediments. *Opehlia* 23(2):101-118.
- Srna, R.F. and A. Baggaley. 1976. Rate of excretion of ammonia by the hard clam *Mercenaria mercenaria* and the American oyster *Crassostrea virginica*. *Mar. Biol.* 36:251-258.

RESULTS AND DISCUSSION

General Description of Sampling Sites

Sediment cores collected from eight different Chesapeake Bay locations were examined for macroinvertebrate biomass (Table 2). These samples were collected from 4 locations along the longitudinal axis of the Chesapeake Bay mainstem and 2 locations each in the Patuxent and Potomac Rivers (Table 1). The upper bay station (Still Pond; SLPD) was characterized by generally low salinity (<5 ppt) and soft sediments with *Rangia* sp. and shell present in some areas. There has been no indication of anoxic/hypoxic conditions at this location (Magnien et al. 1995). The three remaining mainstem bay stations (R-78, R-64, PNPT) were all located in deeper water (> 14 m), had soft sediments, mesohaline bottom water salinity conditions and were hypoxic or anoxic during most summer months in recent years. During early spring benthic macroinfauna were generally evident at these stations but largely disappear by June in most years, presumably due to poor water quality conditions, predation or some combination of both (Magnien et al. 1995). Sediments at R-78 often also contained cinder-like material, possibly material disposed of from steamships in the past. Sediment-water oxygen and nutrient exchanges measured at this site were on occasion much lower than expected for this enriched zone of the bay. We have wondered if a sediment toxicity situation exists in the vicinity of this site, but have not pursued this speculation.

The stations in the Patuxent were located in oligohaline (BUVA) and mesohaline (STLC) zones of the estuary. The upper estuary station was characterized by very turbid water, soft sediments, a large community of benthic macroinvertebrates (e.g. *M. balthica*) and no indication of hypoxic or anoxic bottom waters. The lower estuary site had much clearer water, firmer sediments, some shell and hypoxic bottom waters during portions of some summer months. During some summers dissolved oxygen conditions were relatively good at this location (>3 mg l⁻¹) but during others concentrations fell to very hypoxic levels (< 1 mg l⁻¹; Hagy 1996).

The stations in the Potomac were also located in oligohaline (MDPT) and mesohaline (RGPT) zones of the estuary. The upper estuary station was characterized by turbid water, soft sediments and no indication of hypoxic or anoxic bottom waters. The lower estuary site had much clearer water, firmer sediments, some shell and very hypoxic or anoxic bottom waters from June through August; this was the SONE station having the poorest bottom water dissolved oxygen conditions.

Biomass in Intact Sediment Cores

General Characteristics: Frequency of occurrence plots of benthic macroinvertebrate biomass are provided in Figures 2 and 3 for weight and shell-free dry weight, respectively. The general characteristics of both plots are similar so further comments here refer to the shell-free dry weight presentation (Figure 3). The most common biomass associated with sediment cores fell in the range of 1.0 to 9.9 g m⁻¹. Approximately 34% of all cores had macroinvertebrate biomasses of less than 1.0 g m⁻², a very low value for a rich estuary. Only 14% of the samples had biomass estimates in the range of 10 to 99.9 g m⁻² and only 4 % were greater than 100 g m⁻². The latter two categories, representing 18% of the total number of samples analyzed (45 cores), had benthic macroinvertebrate biomasses which were moderate to large and expected to have a substantial influence on oxygen consumption rates, ammonium excretion rates and other ecological functions.

Spatial Characteristics: Benthic macroinvertebrate biomass estimates from each of the 251 cores examined are provided in Table 8a-8h and organized by station. At the deeper stations, which are generally exposed to summer season hypoxia or anoxia, benthic macroinvertebrate biomass estimates were generally low. The range of values at R-78, R-64, PNPT and RGPT were 0.1 - 2.0, 0.1 - 12.0, 0.1 - 7.0, and 0.1 - 7.0 g m⁻², respectively. The most common biomass estimates at these stations ranged from 0.1 to 4.0 g m⁻². At two of the tributary stations biomass values were generally higher, ranging from 0.1 to 13.0 g m⁻² at MDPT in the upper Potomac and from 0.1 to 27 g m⁻² at STLC in the lower Patuxent River. Commonly encountered values ranged from 0.5 to 10 g m⁻² at these sites. At the remaining two sites (BUVA in the upper Patuxent and SLPD in the upper Chesapeake Bay mainstem) benthic macroinvertebrate biomass estimates were generally larger (frequently encountered values between 10 - 50 g m⁻²) and on occasion values were very large (> 100 g m⁻²). The highest biomass estimates obtained were 137 and 216 g m⁻² at BUVA and SLPD, respectively.

Dominant Organism Groups: At the deeper stations which were generally exposed to seasonal hypoxia or anoxia (R-78, R-64, PNPT and RGPT), benthic macroinvertebrate species were generally of limited abundance; most of the time >90% of the biomass present was accounted for by one or two species, usually small polychaetes such as *Paraprionospio pinnata* and *Strablospio benedicti*. On occasion, isopod (*Lironeca ovalis*) or bivalve (*Mulinia lateralis*) species were also present at these stations. At two of the tributary stations (MDPT in the upper Potomac and STLC in the lower Patuxent River) there was higher diversity in the species assemblage; generally two or three species of amphipods

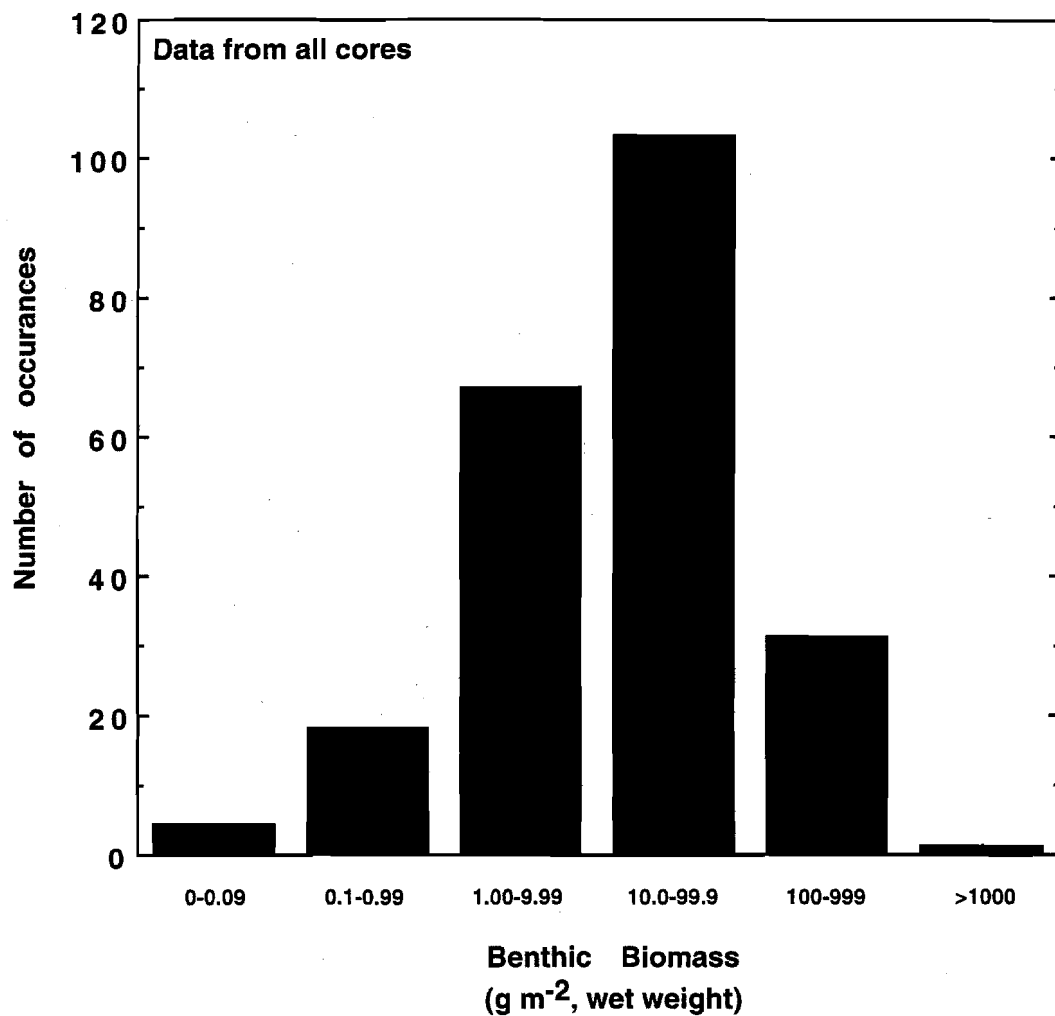


Figure 2. A frequency plot indicating the distribution of benthic macroinvertebrate biomass (g m⁻², wet weight) in sediment cores collected in Chesapeake Bay in connection with the Maryland Chesapeake Bay Water Quality Monitoring Program.

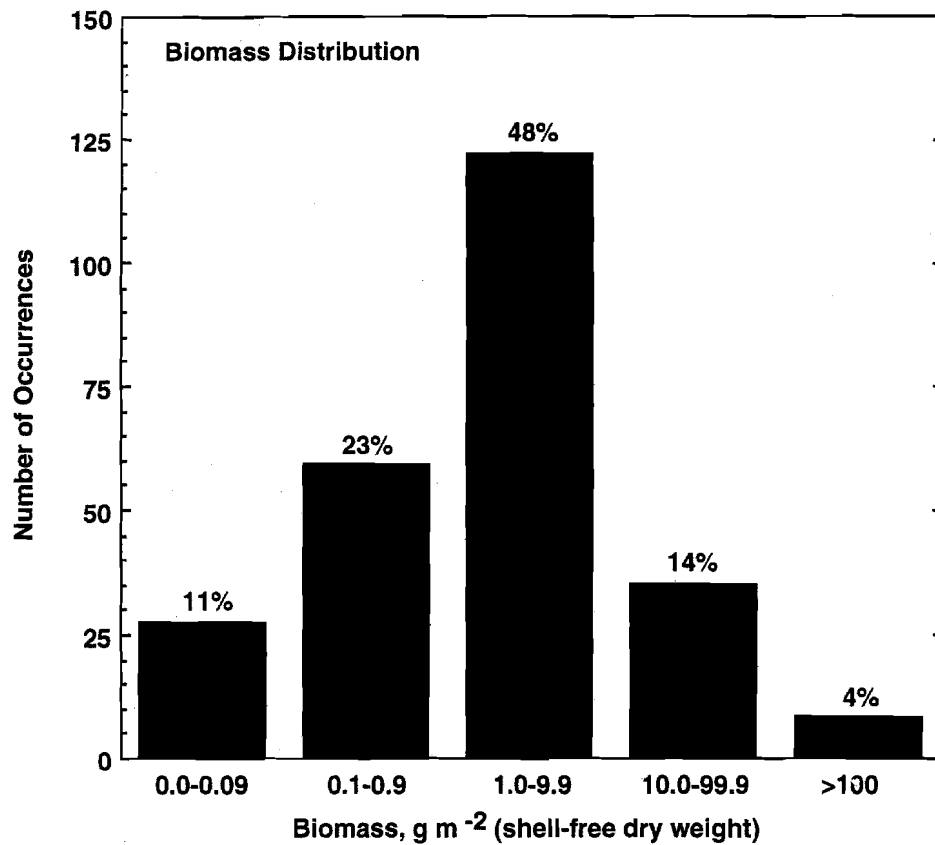


Figure 3. A simple bar graph indicating the distribution of benthic invertebrate biomass (shell-free dry weight) observed in benthic cores. The total number of samples was 251 and the values shown on the tops of the bars represent the percent of the total number of cores falling in a specific biomass category.

Table 8a. A summary of station locations, sampling dates, water column conditions (dissolved oxygen concentrations, temperature and salinity in bottom waters), calculated benthic macroinvertebrate respiration rates, calculated benthic macroinvertebrate ammonium excretion rates, calculated benthic macroinvertebrate biomass, in-situ measured fluxes of SOC and ammonium and calculated percentages of SOC and ammonium flux attributed to benthic macroinvertebrate metabolism. In all cases data have been expressed on a per square meter basis rather than as masses or fluxes related to the area of sediments contained in a sediment core sample. Blank cells indicate either missing data or an inappropriate calculation.

STATION	DATE	CORE REPLICATE	Bottom Water DO (mg/l)	Bottom Water Temp (C)	Bottom Water Sal (ppt)	Calculated	Calculated	Calculated	Measured In-Situ	Measured In-Situ	% of SOC	% of NH4 Flux
						Benthic Invert Respiration	Benthic Invert NH4 Excretion	Benthic Invert Biomass	SOC Flux	NH4 Flux	via Ben Inverts	via Ben Inverts
						[gO2/(m2*day)]	[μMNA/(m2*hr)]	(g/m2, dry wt)	[gO2/(m2*day)]	[μMNA/(m2*hr)]	(%)	(%)
Maryland Point	Aug-85	1	4.5	26.7	7.2	0.175	4.38	0.14	-2.20	543.20	7.9	0.8
Maryland Point	Aug-85	2	4.5	26.7	7.2	0.880	29.83	3.87	-2.81	222.30	31.3	13.4
Maryland Point	Aug-85	3	4.5	26.7	7.2	0.106	2.39	0.10	-2.12	110.70	5.0	2.2
Maryland Point	Oct-85	1	8.1	20.0	8.1	0.114	24.87	0.88	-2.15	550.10	5.3	4.5
Maryland Point	Oct-85	2	8.1	20.0	8.1	0.224	51.65	2.78	-1.94	292.20	11.5	17.7
Maryland Point	Oct-85	3	8.1	20.0	8.1	0.135	29.66	1.07	-2.10	372.20	6.4	8.0
Maryland Point	May-86	1	7.4	15.7	4.8	0.365	52.31	3.79	-1.46	78.70	25.0	66.5
Maryland Point	May-86	2	7.4	15.7	4.8	0.380	50.57	4.27	-1.28	114.20	29.7	44.3
Maryland Point	May-86	3	7.4	15.7	4.8	0.509	67.92	5.70	-1.33	75.80	38.2	89.6
Maryland Point	Jun-86	1	4.9	25.2	6.1	2.231	48.27	2.36	-2.09	106.30	106.8	45.4
Maryland Point	Jun-86	2	4.9	25.2	6.1	1.904	39.10	1.88	-2.03	125.90	93.8	31.1
Maryland Point	Jun-86	3	4.9	25.2	6.1	2.740	65.81	3.46	-1.59	95.70	172.3	68.8
Maryland Point	Aug-86	1	5.4	26.8	7.9	0.342	23.64	2.48	-1.44	384.40	23.7	6.1
Maryland Point	Aug-86	2	5.4	26.8	7.9	0.391	15.23	1.22	-1.36	344.90	28.7	4.4
Maryland Point	Aug-86	3	5.4	26.8	7.9	0.343	11.70	0.69	-1.17	384.90	29.3	3.0
Maryland Point	Nov-86	1	9.2	13.8	9.0	0.032	9.21	0.45	-0.94	186.10	3.4	4.9
Maryland Point	Nov-86	2	9.2	13.8	9.0	0.034	12.17	0.51	-0.80	189.60	4.3	6.4
Maryland Point	Nov-86	3	9.2	13.8	9.0	0.086	38.08	4.95	-1.00	153.00	8.6	24.9
Maryland Point	Apr-87	1	9.0	14.3	0.7	0.047	14.34	1.06	-0.75	0.00	6.3	
Maryland Point	Apr-87	2	9.0	14.3	0.7	0.032	11.57	0.97	-0.87	0.00	3.6	
Maryland Point	Apr-87	3	9.0	14.3	0.7	0.018	5.99	0.34		0.00		
Maryland Point	Jun-87	1	4.1	22.2	6.9	0.070	25.08	2.43	-0.68	144.00	10.3	17.4
Maryland Point	Jun-87	2	4.1	22.2	6.9	0.016	3.23	0.13	-0.51	155.90	3.1	2.1
Maryland Point	Jun-87	3	4.1	22.2	6.9	0.043	10.94	0.37	-0.46	55.10	9.3	19.8
Maryland Point	Aug-87	1	3.6	29.9	6.8	0.805	43.88	4.41	-1.20	271.50	67.1	16.2
Maryland Point	Aug-87	2	3.6	29.9	6.8	1.104	29.74	1.75	-1.62	580.90	68.2	5.1
Maryland Point	Aug-87	3	3.6	29.9	6.8	0.833	43.76	5.22	-1.25	421.30	50.7	10.4
Maryland Point	Nov-87	1	9.9	10.7	10.0	0.021	6.29	0.59	-0.32	40.70	6.5	15.5
Maryland Point	Nov-87	2	9.9	10.7	10.0	0.055	16.40	2.14	-0.44	52.80	12.4	31.1
Maryland Point	Nov-87	3	9.9	10.7	10.0	0.062	26.61	4.48	-0.30	-127.40	20.8	
Maryland Point	Apr-88	1	9.2	12.6	2.3	0.168	86.96	8.47	-0.68	214.70	24.8	40.5
Maryland Point	Apr-88	2	9.2	12.6	2.3	0.162	46.06	3.90	-0.92	54.40	17.6	84.7
Maryland Point	Apr-88	3	9.2	12.6	2.3	0.210	53.77	3.87	-0.75	73.30	28.0	73.4
Maryland Point	Jun-88	1	6.7	20.4	1.4	0.122	35.66	6.79	-0.56	-22.30	21.8	
Maryland Point	Jun-88	2	6.7	20.4	1.4	0.046	6.57	0.58	-0.35	-43.50	13.1	
Maryland Point	Jun-88	3	6.7	20.4	1.4	0.132	20.78	2.49	-0.50	-18.10	26.4	
Maryland Point	Aug-88	1	4.1	28.8	7.6	0.680	22.31	2.10	-1.08	255.10	62.9	8.7
Maryland Point	Aug-88	2	4.1	28.8	7.6	0.925	61.22	12.95	-0.77	150.90	120.2	40.6
Maryland Point	Aug-88	3	4.1	28.8	7.6	0.214	8.34	0.69	-0.93	99.60	23.0	8.4
Maryland Point	Nov-88	1	10.3	11.0	9.5	0.017	3.45	0.27	-0.51	62.00	3.4	5.6
Maryland Point	Nov-88	2	10.3	11.0	9.5	0.011	3.72	0.19	-0.70	247.40	1.6	1.5
Maryland Point	Nov-88	3	10.3	11.0	9.5	0.027	16.81	2.24	-0.91	115.10	3.0	14.6

Table 8b. A summary of station locations, sampling dates, water column conditions (dissolved oxygen concentrations, temperature and salinity in bottom waters), calculated benthic macroinvertebrate respiration rates, calculated benthic macroinvertebrate ammonium excretion rates, calculated benthic macroinvertebrate biomass, in-situ measured fluxes of SOC and ammonium, and calculated percentages of SOC and ammonium flux attributed to benthic macroinvertebrate metabolism. In all cases data have been expressed on a per square meter basis rather than as masses or fluxes related to the area of sediments contained in a sediment core sample. Blank cells indicate either missing data or an inappropriate calculation.												
STATION	DATE	CORE REPLICATE	Bottom Water DO (mol/l)	Bottom Water Temp (C)	Bottom Water Sal (ppt)	Calculated Benthic Invert Respiration [gO2/(m2·day)]	Calculated Benthic Invert NH4 Excretion [μM/(m2·hr)]	Calculated Benthic Invert Biomass (g/m2, dry wt)	Measured In-Situ SOC Flux [gO2/(m2·day)]	Measured In-Situ NH4 Flux [μM/(m2·hr)]	% of SOC via Ben Inverts (%)	% of NH4 Flux via Ben Inverts (%)
Buena Vista	Aug-85	2	3.0	26.1	13.7	1.107	27.10	2.50	-0.61	158.50	181.4	17.1
Buena Vista	Aug-85	3	3.0	26.1	13.7	0.864	26.41	1.37	-0.61	283.20	141.7	9.3
Buena Vista	Oct-85	1	8.2	21.6	13.3	0.224	90.13	2.76	-1.93	222.00	11.6	40.6
Buena Vista	Oct-85	2	8.2	21.6	13.3	0.182	86.12	3.37	-1.21	134.10	15.0	64.2
Buena Vista	Oct-85	3	8.2	21.6	13.3	0.606	196.22	12.27	-2.25	213.60	27.0	91.9
Buena Vista	May-86	1	8.6	19.1	8.8	2.059	276.49	29.56	-3.45	90.90	59.7	304.2
Buena Vista	May-86	2	8.6	19.1	8.8	1.565	211.61	20.77	-3.40	108.30	46.0	195.4
Buena Vista	May-86	3	8.6	19.1	8.8	1.608	270.08	27.24	-2.84	78.30	56.6	344.9
Buena Vista	Jun-86	1	5.4	24.9	11.9	4.684	149.05	11.16	-1.78	361.90	263.2	41.2
Buena Vista	Jun-86	2	5.4	24.9	11.9	4.461	153.38	11.99	-3.00	451.10	148.7	34.0
Buena Vista	Jun-86	3	5.4	24.9	11.9	1.237	87.92	8.71	-2.92	423.10	42.4	20.8
Buena Vista	Aug-86	1	5.8	28.5	11.0	2.997	199.81	56.34	-1.96	416.40	152.9	48.0
Buena Vista	Nov-86	1	9.2	12.8	13.0	0.284	221.48	118.98	-1.15	104.30	24.7	212.3
Buena Vista	Nov-86	2	9.2	12.8	13.0	0.340	265.14	130.09	-0.90	0.00	37.8	
Buena Vista	Nov-86	3	9.2	12.8	13.0	0.287	190.00	77.22	-0.83	0.00	34.6	
Buena Vista	Apr-87	1	10.5	16.1	9.2	0.776	207.45	24.26	-1.47	245.40	52.8	84.5
Buena Vista	Apr-87	2	10.5	16.1	9.2	0.996	217.46	20.27	-1.69	195.30	58.9	111.3
Buena Vista	Apr-87	3	10.5	16.1	9.2	0.890	150.86	12.35	-1.17	148.90	76.0	101.3
Buena Vista	Jun-87	2	5.5	25.7	9.7	2.900	210.88	25.90	-3.28	394.60	88.4	53.4
Buena Vista	Jun-87	3	5.5	25.7	9.7	3.420	305.15	50.81	-2.51	333.90	136.3	91.4
Buena Vista	Aug-87	1	3.3	28.7	11.8	2.606	133.63	44.85	-0.72	150.70	361.9	88.7
Buena Vista	Aug-87	22	3.3	28.7	11.8	2.942	112.61	32.96	-0.99	164.00	297.2	68.7
Buena Vista	Aug-87	23	3.3	28.7	11.8	1.150	16.25	1.69	-0.99	164.00	116.2	9.9
Buena Vista	Aug-87	33	3.3	28.7	11.8	2.090	140.03	54.40	-1.08	208.60	193.5	67.1
Buena Vista	Aug-87	34	3.3	28.7	11.8	0.795	138.20	58.67	-1.08	208.60	73.6	66.3
Buena Vista	Nov-87	1	10.6	10.4	13.5	0.485	218.51	84.91	-1.02	36.40	47.5	600.3
Buena Vista	Nov-87	2	10.6	10.4	13.5	0.295	183.91	80.81	-0.51	-52.60	57.8	
Buena Vista	Nov-87	3	10.6	10.4	13.5	0.377	158.44	48.02	-1.01	34.60	37.4	457.9
Buena Vista	Apr-88	1	9.2	12.4	9.7	0.996	398.57	100.79	-1.45	76.50	68.7	521.0
Buena Vista	Apr-88	3	9.2	12.4	9.7	1.032	425.54	136.87	-2.12	195.70	48.7	217.4
Buena Vista	Jun-88	1	4.9	20.4	9.3	1.390	307.05	68.66	-1.60	305.20	86.9	100.6
Buena Vista	Jun-88	2	4.9	20.4	9.3	1.715	277.74	50.92	-1.58	307.80	108.5	90.2
Buena Vista	Jun-88	3	4.9	20.4	9.3	1.662	357.71	88.79	-1.23	260.80	135.1	137.2
Buena Vista	Aug-88	1	2.2	27.6	11.4	1.806	44.55	7.62	-0.76	256.30	237.6	17.4
Buena Vista	Aug-88	2	2.2	27.6	11.4	4.557	257.85	87.30	-0.95	232.00	479.7	111.1
Buena Vista	Aug-88	3	2.2	27.6	11.4	2.158	71.65	17.69	-0.71	154.70	304.0	46.3
Buena Vista	Nov-88	1	9.4	11.9	14.1	0.374	210.54	57.72	-1.39	37.20	26.9	566.0
Buena Vista	Nov-88	2	9.4	11.9	14.1	0.331	172.82	51.03	-1.09		30.3	
Buena Vista	Nov-88	3	9.4	11.9	14.1	0.303	185.84	65.01	-1.12	13.80	27.1	1346.7

Table 8c. A summary of station locations, sampling dates, water column conditions (dissolved oxygen concentrations, temperature and salinity in bottom waters), calculated benthic macroinvertebrate respiration rates, calculated benthic macroinvertebrate ammonium excretion rates, calculated benthic macroinvertebrate biomass, in-situ measured fluxes of SOC and ammonium and calculated percentages of SOC and ammonium flux attributed to benthic macroinvertebrate metabolism. In all cases data have been expressed on a per square meter basis rather than as masses or fluxes related to the area of sediments contained in a sediment core sample. Blank cells indicate either missing data or an inappropriate calculation.

STATION	DATE	CORE REPLICATE	Bottom Water DO (mg/l)	Bottom Water Temp (C)	Bottom Water Sal (ppt)	Calculated	Calculated	Calculated	Measured In-Situ SOC Flux [gO2/(m2*day)]	Measured In-Situ NH4 Flux [μMN/(m2*hr)]	% of SOC via Ben Inverts (%)	% of NH4 Flux via Ben Inverts (%)
						Benthic Invert Respiration [gO2/(m2*day)]	Benthic Invert NH4 Excretion [μMN/(m2*hr)]	Benthic Invert Biomass (g/m2, dry wt)				
Point No Point	Aug-85	1	2.3	26.1	19.9	9.862	58.66	7.26	-1.12	220.60	880.6	26.6
Point No Point	Oct-85	1	5.8	20.4	19.9	0.189	23.09	1.93	-0.78	81.10	24.3	28.5
Point No Point	Oct-85	3	5.8	20.4	19.9	0.290	35.09	3.77	-1.20	39.30	24.1	89.3
Point No Point	Aug-87	2	0.9	27.0	18.0	0.024	0.77	0.06	-0.36	105.20	6.7	0.7
Point No Point	Nov-87	1	9.9	12.4	19.9	0.031	8.75	0.51	-0.44	23.50	7.0	37.2
Point No Point	Nov-87	2	9.9	12.4	19.9	0.093	20.76	2.38	-0.60	36.50	15.6	56.9
Point No Point	Nov-87	3	9.9	12.4	19.9	0.052	14.12	0.93	-0.94	61.30	5.5	23.0
Point No Point	Apr-88	1	10.3	11.2	16.9	0.032	9.57	0.60	-0.20	8.30	15.8	115.2
Point No Point	Apr-88	2	10.3	11.2	16.9	0.018	4.90	0.29	-0.70	8.10	2.5	60.4
Point No Point	Apr-88	3	10.3	11.2	16.9	0.055	17.24	2.20	-0.76	8.60	7.2	200.5
Point No Point	Jun-88	1	4.1	18.9	15.8	0.071	8.00	1.75	-0.91	200.60	7.8	4.0
Point No Point	Jun-88	2	4.1	18.9	15.8	0.004	0.84	0.03	-0.65	139.10	0.6	0.6
Point No Point	Jun-88	3	4.1	18.9	15.8	0.002	0.35	0.02	-0.48	88.20	0.4	0.4
Point No Point	Aug-88	2	0.0	26.0	17.8	0.022	0.87	0.08	0.00	107.60		0.8
Point No Point	Nov-88	1	10.6	13.0	19.2	0.059	17.62	1.64	-0.60	66.40	9.9	26.5
Point No Point	Nov-88	2	10.6	13.0	19.2	0.050	18.15	0.85	-0.43	126.00	11.6	14.4
Point No Point	Nov-88	3	10.6	13.0	19.2	0.046	17.89	0.92	-0.54	104.70	8.6	17.1

Table 8d. A summary of station locations, sampling dates, water column conditions (dissolved oxygen concentrations, temperature and salinity in bottom waters), calculated benthic macroinvertebrate respiration rates, calculated benthic macroinvertebrate ammonium excretion rates, calculated benthic macroinvertebrate biomass, in-situ measured fluxes of SOC and ammonium and calculated percentages of SOC and ammonium flux attributed to benthic macroinvertebrate metabolism. In all cases data have been expressed on a per square meter basis rather than as masses or fluxes related to the area of sediments contained in a sediment core sample. Blank cells indicate either missing data or an inappropriate calculation.

STATION	DATE	CORE REPLICATE	Bottom Water DO (mg/l)	Bottom Water Temp (C)	Bottom Water Sal (ppt)	Calculated	Calculated	Calculated	Measured In-Situ	Measured In-Situ	% of SOC	% of NH4 Flux
						Benthic Invert Respiration [gO2/(m2*day)]	Benthic Invert NH4 Excretion [μMN/(m2*hr)]	Benthic Invert Biomass [g/m2, dry wt]	SOC Flux [gO2/(m2*day)]	NH4 Flux [μMN/(m2*hr)]	via Ben Inverts [%]	via Ben Inverts [%]
Ragged Point	Oct-85	1	5.2	20.2	18.3	0.014	2.74	0.11	-0.84	402.00	1.7	0.7
Ragged Point	Oct-85	2	5.2	20.2	18.3	0.007	1.70	0.05	-0.85	401.90	0.8	0.4
Ragged Point	Oct-85	3	5.2	20.2	18.3	0.010	2.77	0.06	-0.88	425.30	1.1	0.7
Ragged Point	May-86	1	5.8	12.8	13.3	1.050	122.43	7.58	-2.44	546.60	43.0	22.4
Ragged Point	May-86	2	5.8	12.8	13.3	1.118	96.12	4.20	-1.97	330.00	56.8	29.1
Ragged Point	May-86	3	5.8	12.8	13.3	1.496	103.34	3.84	-2.62	292.10	57.1	35.4
Ragged Point	Apr-87	1	7.3	11.2	14.2	0.274	28.68	0.94	-0.56	68.80	48.9	41.7
Ragged Point	Apr-87	2	7.3	11.2	14.2	0.299	39.42	1.84	-0.73	111.70	41.0	35.3
Ragged Point	Apr-87	3	7.3	11.2	14.2	0.350	68.72	5.44	-0.64	118.00	54.7	58.2
Ragged Point	Jun-87	1	0.1	18.4	17.2	0.031	2.56	0.14	0.00	100.90		2.5
Ragged Point	Jun-87	2	0.1	18.4	17.2	0.002	0.35	0.02	0.00	83.80		0.4
Ragged Point	Aug-87	1	0.3	26.7	15.7	0.016	0.35	0.02	0.00	524.30		0.1
Ragged Point	Nov-87	1	9.9	12.0	17.7	0.021	7.43	0.29	-0.71	46.40	2.9	16.0
Ragged Point	Nov-87	2	9.9	12.0	17.7	0.139	40.94	4.45	-0.64	29.60	21.7	138.3
Ragged Point	Nov-87	3	9.9	12.0	17.7	0.034	10.63	0.55	-0.53	56.80	6.4	18.7
Ragged Point	Apr-88	2	11.7	11.5	13.5	0.192	19.41	0.84	-0.98	0.00	19.6	
Ragged Point	Apr-88	3	11.7	11.5	13.5	0.163	14.35	0.59	-0.92	0.00	17.7	
Ragged Point	Jun-88	1	0.1	18.3	14.0	0.014	1.96	0.14	-0.22	319.60	6.3	0.6
Ragged Point	Jun-88	2	0.1	18.3	14.0	0.019	2.61	0.19	-0.07	239.80	26.6	1.1
Ragged Point	Jun-88	3	0.1	18.3	14.0	0.002	0.48	0.02	-0.16	384.90	1.4	0.1
Ragged Point	Nov-88	1	9.7	12.1	18.2	0.035	7.89	0.30	-0.75	44.00	4.7	17.9
Ragged Point	Nov-88	2	9.7	12.1	18.2	0.028	6.25	0.25	-0.73	30.20	3.8	20.7
Ragged Point	Nov-88	3	9.7	12.1	18.2	0.035	9.22	0.52	-0.68	31.20	5.2	29.5

Table 8e. A summary of station locations, sampling dates, water column conditions (dissolved oxygen concentrations, temperature and salinity in bottom waters), calculated benthic macroinvertebrate respiration rates, calculated benthic macroinvertebrate ammonium excretion rates, calculated benthic macroinvertebrate biomass, in-situ measured fluxes of SOC and ammonium and calculated percentages of SOC and ammonium flux attributed to benthic macroinvertebrate metabolism. In all cases data have been expressed on a per square meter basis rather than as masses or fluxes related to the area of sediments contained in a sediment core sample. Blank cells indicate either missing data or an inappropriate calculation.

STATION	DATE	CORE REPLICATE	Bottom Water DO (mg/l)	Bottom Water Temp (C)	Bottom Water Sal (ppt)	Calculated	Calculated	Calculated	Measured In-Situ SOC Flux [gO2/(m2*day)]	Measured In-Situ NH4 Flux [μMN/(m2*hr)]	% of SOC via Ben Inverts (%)	% of NH4 Flux via Ben Inverts (%)
						Benthic Invert Respiration [gO2/(m2*day)]	Benthic Invert NH4 Excretion [μMN/(m2*hr)]	Benthic Invert Biomass (g/m2, dry wgt)				
St. Leonard's Creek	Aug-85	1	4.4	26.3	15.3	0.711	35.41	3.93	-0.79	170.80	90.0	20.7
St. Leonard's Creek	Aug-85	2	4.4	26.3	15.3	1.074	33.39	2.26	-1.15	147.90	93.4	22.6
St. Leonard's Creek	Aug-85	3	4.4	26.3	15.3	0.231	22.02	2.53	-1.22	156.40	18.9	14.1
St. Leonard's Creek	Oct-85	1	7.0	20.4	17.0	0.499	62.59	6.72	-0.68	81.30	73.4	77.0
St. Leonard's Creek	Oct-85	2	7.0	20.4	17.0	0.476	61.62	5.27	-1.01	119.90	47.2	51.4
St. Leonard's Creek	May-86	1	7.5	14.4	12.3	0.208	64.69	9.44	-1.07	31.10	19.5	208.0
St. Leonard's Creek	May-86	2	7.5	14.4	12.3	0.287	85.19	17.00	-1.30	46.50	22.0	183.2
St. Leonard's Creek	May-86	3	7.5	14.4	12.3	0.125	23.61	1.91	-1.04	32.00	12.0	73.8
St. Leonard's Creek	Jun-86	1	5.9	24.5	13.7	1.735	42.33	2.17	-2.88	226.30	60.2	18.7
St. Leonard's Creek	Jun-86	2	5.9	24.5	13.7	2.081	65.65	4.72	-2.84	241.10	73.3	27.2
St. Leonard's Creek	Jun-86	3	5.9	24.5	13.7	2.134	64.50	4.15	-3.17	316.70	67.3	20.4
St. Leonard's Creek	Aug-86	1	4.1	27.0	13.1	0.256	6.66	0.43		172.80		3.9
St. Leonard's Creek	Aug-86	2	4.1	27.0	13.1	0.168	3.27	0.17		170.20		1.9
St. Leonard's Creek	Aug-86	3	4.1	27.0	13.1	0.045	1.21	0.03		116.90		1.0
St. Leonard's Creek	Nov-86	1	9.1	14.0	16.3	0.062	62.45	11.01	-0.51	0.00	12.1	
St. Leonard's Creek	Nov-86	2	9.1	14.0	16.3	0.037	9.80	0.54	-0.59	0.00	6.2	
St. Leonard's Creek	Nov-86	3	9.1	14.0	16.3	0.087	20.20	1.61	-0.43	-17.10	20.3	
St. Leonard's Creek	Apr-87	1	13.0	14.2	11.9	0.346	39.37	2.31	-1.18	21.70	29.3	181.4
St. Leonard's Creek	Apr-87	2	13.0	14.2	11.9	0.639	130.98	18.27	-1.47	28.10	43.5	466.1
St. Leonard's Creek	Apr-87	3	13.0	14.2	11.9	0.293	30.70	1.42	-1.22		24.0	
St. Leonard's Creek	Jun-87	1	1.9	21.3	14.3	0.250	29.44	3.54	-0.52		48.0	
St. Leonard's Creek	Jun-87	2	1.9	21.3	14.3	0.407	51.56	9.55	-0.73	136.10	55.7	37.9
St. Leonard's Creek	Jun-87	3	1.9	21.3	14.3	0.528	98.51	26.71	-1.08	217.00	48.9	45.4
St. Leonard's Creek	Aug-87	1	4.5	27.7	13.2	1.271	31.70	2.29	-0.70	166.00	181.5	19.1
St. Leonard's Creek	Aug-87	2	4.5	27.7	13.2	0.665	14.74	0.97	-0.75	165.90	88.7	8.9
St. Leonard's Creek	Aug-87	3	4.5	27.7	13.2	3.296	39.47	4.01	-0.82	326.20	402.0	12.1
St. Leonard's Creek	Nov-87	1	10.0	12.3	16.4	0.252	61.13	8.38	-0.81	56.80	31.2	107.6
St. Leonard's Creek	Nov-87	2	10.0	12.3	16.4	0.136	33.92	3.19	-0.38	14.90	35.7	227.7
St. Leonard's Creek	Nov-87	3	10.0	12.3	16.4	0.134	45.30	5.02	-0.53	4.70	25.2	963.9
St. Leonard's Creek	Apr-88	1	12.0	12.0	11.5	0.262	58.42	5.10	-1.07	19.10	24.5	305.9
St. Leonard's Creek	Apr-88	2	12.0	12.0	11.5	0.082	21.46	1.44	-1.05	0.00	7.8	
St. Leonard's Creek	Apr-88	3	12.0	12.0	11.5	0.381	54.35	3.14	-1.01	38.20	37.7	142.3
St. Leonard's Creek	Jun-88	1	5.8	20.6	11.0	0.574	32.28	2.65	-0.78	136.50	73.6	23.6
St. Leonard's Creek	Jun-88	2	5.8	20.6	11.0	0.686	34.50	3.04	-0.65	175.40	105.6	19.7
St. Leonard's Creek	Jun-88	3	5.8	20.6	11.0	0.854	45.30	3.69	-0.95	130.50	89.9	34.7
St. Leonard's Creek	Aug-88	1	3.9	27.7	13.5	0.110	2.48	0.13	-0.76	214.60	14.5	1.2
St. Leonard's Creek	Aug-88	2	3.9	27.7	13.5	0.133	3.49	0.21	-0.77	194.60	17.3	1.8
St. Leonard's Creek	Aug-88	3	3.9	27.7	13.5	0.064	1.70	0.11	-1.02	281.30	6.3	0.6
St. Leonard's Creek	Nov-88	1	9.0	13.3	16.9	0.138	47.54	3.26	-1.71	0.00	8.0	
St. Leonard's Creek	Nov-88	3	9.0	13.3	16.9	0.148	43.48	2.36	-2.14	0.00	6.9	

Table 8f. A summary of station locations, sampling dates, water column conditions (dissolved oxygen concentrations, temperature and salinity in bottom waters), calculated benthic macroinvertebrate respiration rates, calculated benthic macroinvertebrate ammonium excretion rates, calculated benthic macroinvertebrate biomass, in-situ measured fluxes of SOC and ammonium and calculated percentages of SOC and ammonium flux attributed to benthic macroinvertebrate metabolism. In all cases data have been expressed on a per square meter basis rather than as masses or fluxes related to the area of sediments contained in a sediment core sample. Blank cells indicate either missing data or an inappropriate calculation.

STATION	DATE	CORE REPLICATE	Bottom Water DO (mg/l)	Bottom Water Temp (C)	Bottom Water Sal (ppt)	Calculated	Calculated	Calculated	Measured In-Situ	Measured In-Situ	% of SOC	% of NH4 Flux
						Benthic Invert Respiration [gO2/(m2*day)]	Benthic Invert NH4 Excretion [μMN/(m2*hr)]	Benthic Invert Biomass [g/m2, dry wt]	SOC Flux [gO2/(m2*day)]	NH4 Flux [μMN/(m2*hr)]	via Ben Inverts (%)	via Ben Inverts (%)
Still Pond	Aug-85	1	4.7	26.2	6.3	0.119	26.78	2.81	-1.19	186.10	10.0	14.4
Still Pond	Aug-85	2	4.7	26.2	6.3	0.143	33.39	3.16	-1.26	89.40	11.4	37.4
Still Pond	Aug-85	3	4.7	26.2	6.3	0.059	14.49	1.53	-1.04	75.30	5.7	19.2
Still Pond	Oct-85	1	6.9	18.5	7.1	0.154	33.79	2.98	-0.90	60.40	17.1	56.0
Still Pond	Oct-85	2	6.9	18.5	7.1	0.067	17.13	1.56	-0.66		10.2	
Still Pond	Oct-85	3	6.9	18.5	7.1	0.135	36.20	2.48	-0.78	26.90	17.3	134.6
Still Pond	May-86	1	9.1	14.4	0.2	0.144	41.62	2.33	-1.53	160.90	9.4	25.9
Still Pond	May-86	2	9.1	14.4	0.2	0.289	71.93	5.59	-1.65	125.30	17.5	57.4
Still Pond	May-86	3	9.1	14.4	0.2	0.297	71.31	6.50	-1.12	82.00	26.5	87.0
Still Pond	Jun-86	1	6.2	24.2	3.0	0.567	720.56	163.96	-2.43	154.50	23.3	466.4
Still Pond	Jun-86	2	6.2	24.2	3.0	0.408	138.60	9.48	-2.12	88.60	19.3	156.4
Still Pond	Jun-86	3	6.2	24.2	3.0	0.297	86.07	4.89	-1.85	68.30	16.1	126.0
Still Pond	Aug-86	1	4.6	25.1	7.0	0.050	15.71	1.06	-1.22	513.00	4.1	3.1
Still Pond	Aug-86	2	4.6	25.1	7.0	0.100	30.22	2.65	-0.77	264.60	12.9	11.4
Still Pond	Aug-86	3	4.6	25.1	7.0	0.235	65.25	9.07	-0.41	147.50	57.3	44.2
Still Pond	Nov-86	1	8.5	12.8	7.3	0.198	52.31	3.94	-0.87		22.8	
Still Pond	Nov-86	2	8.5	12.8	7.3	0.150	41.70	3.15	-0.85	55.70	17.7	74.9
Still Pond	Nov-86	3	8.5	12.8	7.3	0.161	43.16	2.51	-0.67	-21.10	24.0	
Still Pond	Apr-87	2	7.0	11.1	6.2	0.328	97.92	7.49	-0.37	88.90	88.6	110.1
Still Pond	Apr-87	3	7.0	11.1	6.2	0.344	106.04	7.48	-1.01	48.60	34.0	218.2
Still Pond	Jun-87	1	4.5	21.6	5.5	0.770	143.19	7.46	-1.57	0.00	49.1	
Still Pond	Jun-87	2	4.5	21.6	5.5	0.635	138.18	7.39	-1.39	0.00	45.7	
Still Pond	Jun-87	3	4.5	21.6	5.5	0.935	150.63	7.76	-1.32	0.00	70.9	
Still Pond	Aug-87	1	5.5	27.6	6.2	0.141	30.57	3.78	-1.08	49.10	13.1	62.3
Still Pond	Aug-87	2	5.5	27.6	6.2	0.138	28.72	3.62	-1.11	61.20	12.5	46.9
Still Pond	Aug-87	3	5.5	27.6	6.2	0.202	45.97	6.39	-0.83	73.30	24.3	62.7
Still Pond	Nov-87	1	9.9	11.5	2.4	0.115	29.32	2.74	-0.63	-28.00	18.3	
Still Pond	Nov-87	2	9.9	11.5	2.4	0.043	11.48	0.87	-0.38	-19.10	11.4	
Still Pond	Nov-87	3	9.9	11.5	2.4	0.195	293.93	216.05	-0.69	44.30	28.2	663.5
Still Pond	Apr-88	1	10.0	11.5	1.8	0.271	62.30	8.08	-0.55	79.30	49.2	78.6
Still Pond	Apr-88	2	10.0	11.5	1.8	0.414	407.21	201.99	-0.73	37.00	56.7	1100.6
Still Pond	Apr-88	3	10.0	11.5	1.8	0.164	38.52	3.91	-0.73	43.60	22.5	88.3
Still Pond	Jun-88	2	4.8	19.5	4.2	0.090	25.43	2.42	-0.48	135.20	18.7	18.8
Still Pond	Jun-88	3	4.8	19.5	4.2	0.052	21.30	1.72	-0.36	107.70	14.4	19.8
Still Pond	Aug-88	1	6.8	29.1	3.2	0.125	30.18	3.37	-0.81	119.50	15.4	25.3
Still Pond	Aug-88	2	6.8	29.1	3.2	0.113	194.77	172.23	-0.80		14.2	
Still Pond	Aug-88	3	6.8	29.1	3.2	0.100	30.77	4.24	-0.82	120.20	12.2	25.6
Still Pond	Nov-88	1	10.0	11.4	9.1	0.025	6.99	0.51	-0.28	0.00	9.0	
Still Pond	Nov-88	2	10.0	11.4	9.1	0.036	10.51	1.22	-0.25	0.00	14.5	
Still Pond	Nov-88	3	10.0	11.4	9.1	0.031	7.16	0.57	-0.19	0.00	16.2	

Table 8g. A summary of station locations, sampling dates, water column conditions (dissolved oxygen concentrations, temperature and salinity in bottom waters), calculated benthic macroinvertebrate respiration rates, calculated benthic macroinvertebrate ammonium excretion rates, calculated benthic macroinvertebrate biomass, in-situ measured fluxes of SOC and ammonium and calculated percentages of SOC and ammonium flux attributed to benthic macroinvertebrate metabolism. In all cases data have been expressed on a per square meter basis rather than as masses or fluxes related to the area of sediments contained in a sediment core sample. Blank cells indicate either missing data or an inappropriate calculation.

STATION	DATE	CORE REPLICATE	Bottom Water DO (mg/l)	Bottom Water Temp (C)	Bottom Water Sal (ppt)	Calculated	Calculated	Calculated	Measured In-Situ SOC Flux [gO ₂ /(m ² ·day)]	Measured In-Situ NH ₄ Flux [μMN/(m ² ·hr)]	% of SOC via Ben Inverts (%)	% of NH ₄ Flux via Ben Inverts (%)
						Benthic Invert Respiration [gO ₂ /(m ² ·day)]	Benthic Invert NH ₄ Excretion [μMN/(m ² ·hr)]	Benthic Invert Biomass (g/m ² , dry wt)				
R 64	Aug-85	1	0.8	25.6	23.4	1.324	30.10	1.06	-2.04	361.30	64.9	8.3
R 64	Aug-85	2	0.8	25.6	23.4	0.083	1.90	0.06	-2.32	324.80	3.6	0.6
R 64	Aug-85	3	0.8	25.6	23.4	3.903	88.34	4.67	-2.48	465.50	157.4	19.0
R 64	Oct-85	1	4.0	21.1	21.2	0.036	6.02	0.32	-1.29	351.70	2.8	1.7
R 64	Oct-85	2	4.0	21.1	21.2	0.037	6.68	0.31	-1.57	385.50	2.4	1.7
R 64	Oct-85	3	4.0	21.1	21.2	0.028	5.35	0.22	-1.18	296.80	2.4	1.8
R 64	Jun-86	1	0.0	20.4	18.7	0.413	39.42	4.99	-0.48	524.90	86.0	7.5
R 64	Jun-86	2	0.0	20.4	18.7	0.986	89.87	10.82	-0.51	508.20	193.4	17.7
R 64	Jun-86	3	0.0	20.4	18.7	0.444	60.14	5.37	-0.14		316.9	
R 64	Aug-86	1	0.1	26.1	17.8	0.016	0.35	0.02	-0.12	631.10	13.2	0.1
R 64	Aug-86	2	0.1	26.1	17.8	0.016	0.35	0.02	0.00	518.20		0.1
R 64	Aug-86	3	0.1	26.1	17.8	0.022	0.87	0.08	0.00	948.70		0.1
R 64	Nov-86	1	6.4	16.0	19.9	0.006	1.32	0.05	-0.51	71.30	1.3	1.8
R 64	Nov-86	2	6.4	16.0	19.9	0.042	6.87	0.39	-0.60	80.30	7.0	8.6
R 64	Nov-86	3	6.4	16.0	19.9	0.022	3.90	0.19	-0.83	116.20	2.7	3.4
R 64	Apr-87	1	7.4	9.4	18.0	1.284	87.95	2.71	-0.49	33.00	262.1	266.5
R 64	Apr-87	2	7.4	9.4	18.0	0.000	0.00	0.00	-0.60	64.80	0.0	0.0
R 64	Apr-87	3	7.4	9.4	18.0	0.644	54.73	2.13	-0.69	19.50	93.3	280.7
R 64	Jun-87	1	0.1	16.9	19.2	2.199	108.06	12.24	-0.10	128.90	2198.7	83.8
R 64	Jun-87	2	0.1	16.9	19.2	2.473	81.21	6.16	-1.06	255.50	233.3	31.8
R 64	Jun-87	3	0.1	16.9	19.2	1.973	95.26	10.39	-0.25	152.40	789.3	62.5
R 64	Nov-87	1	8.7	12.8	19.5	0.036	11.15	0.59	-0.42	44.30	8.7	25.2
R 64	Nov-87	2	8.7	12.8	19.5	0.017	5.31	0.26	-0.43	46.50	4.0	11.4
R 64	Nov-87	3	8.7	12.8	19.5	0.003	1.20	0.05	-0.51	34.10	0.7	3.5
R 64	Apr-88	1	7.8	10.9	17.9	0.097	16.88	1.01	-0.58	25.40	16.7	66.5
R 64	Apr-88	2	7.8	10.9	17.9	0.226	36.12	3.30	-0.51	80.10	44.3	45.1
R 64	Apr-88	3	7.8	10.9	17.9	0.111	18.07	0.98	-0.48	42.00	23.2	43.0
R 64	Jun-88	1	0.1	15.6	18.5	0.085	14.62	1.75	-0.14	276.50	61.0	5.3
R 64	Jun-88	3	0.1	15.6	18.5	0.022	3.49	0.21	-0.14	222.50	15.6	1.6

Table 8h. A summary of station locations, sampling dates, water column conditions (dissolved oxygen concentrations, temperature and salinity in bottom waters), calculated benthic macroinvertebrate respiration rates, calculated benthic macroinvertebrate ammonium excretion rates, calculated benthic macroinvertebrate biomass, in-situ measured fluxes of SOC and ammonium and calculated percentages of SOC and ammonium flux attributed to benthic macroinvertebrate metabolism. In all cases data have been expressed on a per square meter basis rather than as masses or fluxes related to the area of sediments contained in a sediment core sample. Blank cells indicate either missing data or an inappropriate calculation.

STATION	DATE	CORE REPLICATE	Bottom Water DO (mg/l)	Bottom Water Temp (C)	Bottom Water Sal (ppt)	Calculated	Calculated	Calculated	Measured In-Situ SOC Flux [gO2/(m2*day)]	Measured In-Situ NH4 Flux [uMN/(m2*hr)]	% of SOC via Ben Inverts (%)	% of NH4 Flux via Ben Inverts (%)
						Benthic Invert Respiration [gO2/(m2*day)]	Benthic Invert NH4 Excretion [uMN/(m2*hr)]	Benthic Invert Biomass (g/m2, dry wgt)				
R-78	Aug-85	1	0.3	25.7	21.3	0.230	5.49	0.29	-0.97	100.20	23.7	5.5
R-78	Aug-85	2	0.3	25.7	21.3	0.360	10.79	0.58		91.70		11.8
R-78	Aug-85	3	0.3	25.7	21.3	0.235	5.39	0.21	-1.05	56.10	22.3	9.6
R-78	Oct-85	1	3.1	20.6	18.3	0.288	52.50	2.32	-0.63	85.70	45.7	61.3
R-78	Oct-85	2	3.1	20.6	18.3	0.120	20.08	0.91	-0.85	76.80	14.1	26.1
R-78	May-86	1	1.7	10.4	17.5	0.086	19.27	1.19	-1.10		7.8	
R-78	May-86	2	1.7	10.4	17.5	0.073	16.49	1.23	-0.61	28.40	12.0	58.1
R-78	May-86	3	1.7	10.4	17.5	0.045	8.88	0.30	-0.66		6.7	

(*Leptoceirus plumulosus*), polychaetes (*Paraprionospio pinnata* and *Strablospio benedicti*), gastropods (*Acteocina canaliculata*) or bivalves (*Macoma balthica* and *Mulinia lateralis*) made up > 90% of the biomass. In addition, at various times amphipods and bivalves were the dominant species at these sites rather than polychaetes which was consistently the case at the deeper stations. At the remaining two sites (BUVA in the upper Patuxent and SLPD in the upper Chesapeake Bay mainstem) benthic species diversity was even greater, especially at the station in the upper Patuxent (BUVA). At this site three to six species (e.g. amphipod *Leptocheirus plumulosus*; isopod *Cyathura polita*) were needed to account for >90% of the biomass and this was the only station where bivalves (*Macoma balthica*) were often the dominant species.

Calculated Rates of Oxygen Consumption by Benthic Macroinvertebrates

General Characteristics: A frequency of occurrence plot of benthic macroinvertebrate respiration expressed as percent catagories of total SOC is provided in Figure 4. The most common contribution of macrofaunal respiration to total SOC is in the range of 0 to 10% and this occurred in about 31% of the samples analyzed. Approximately 63% of samples had macrofaunal respiration less than 30% of total SOC. Only 26% of all samples had macrofaunal respiration greater than 30% of total SOC but less than 100%. Based on the calculated macroinvertebrate respiration rates, 28 samples (11% of total) had rates which exceeded the total SOC.

There appears to be general agreement between the distribution of these rates (expressed as % of total SOC) and biomass data (Figures 2 and 3) as expected because estimation of macrofaunal respiration is directly proportional to biomass. In this accounting, macrofauna contributed a small to modest amount to total sediment SOC. In an earlier examination of this issue by Kemp and Boynton (1981) the authors found that macrofaunal respiration contributed from 1 - 39% of total SOC based on data collected in the Calvert Cliffs region of the mainstem bay (samples were collected in 3 and 6 m depth areas). Seasonally, macrofaunal respiration was most important during late spring (May - June) averaging about 25% of total SOC, less important during early spring and summer (averaging about 10% of total SOC) and very small during the winter. During the spring periods when macrofaunal contributions to SOC were relatively large, macrofaunal biomass was also relatively large, ranging from 15 - 40 g m⁻² (ash-free dry weight). These biomass estimates are within the second highest catagory encountered in the present study which were found in only 14% of samples (Figure 3).

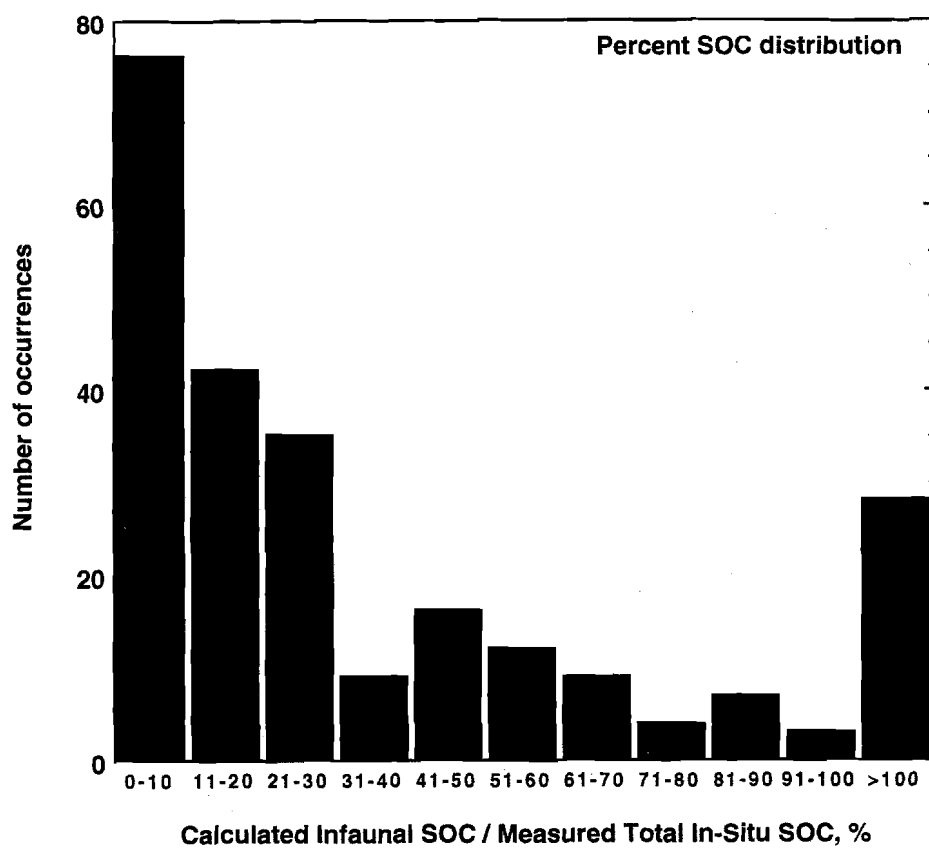


Figure 4. A simple bar graph indicating the distribution of percent of total SOC attributable to benthic infauna. The total number of samples was 251.

The fact that so few (11%) of the calculated macrofaunal respiration rates were >100% of measured total SOC is comforting and suggests that reasonable algorithms were used in developing these first approximations of the relative contribution of macrofauna to total sediment respiration. The fact that some calculations yielded macrofaunal respiration rates of >100% of total SOC is not surprising in view of the fact that (1) temperatures in-situ and those used in algorithms not exactly the same; (2) animal species sampled in the field were not generally the same as those used to develop the respiration algorithms because data for those species does not exist and (3) nothing was known about the condition of macrofaunal species at the time of measurement. They may have been healthy or stressed due to poor DO or some other environmental conditions. Likewise, there is always room for suspicion about the realism of laboratory-based estimates of rates such as respiration or excretion. Overall, this analysis indicates a small contribution by macrofauna to total SOC in most samples (0-20%) and a modest to large contribution (50-100%) in a small number of samples where macrofaunal biomass was relatively large ($> 10 \text{ g m}^{-2}$; shell-free dry weight).

Relationships to Benthic Macroinvertebrate Biomass: Calculated macrofaunal respiration rates and these rates expressed as a percentage of total SOC were plotted as a function of benthic macrofaunal biomass (g m^{-2} , shell-free dry weight) and are shown in Figure 5. The positive general shape of these scattergrams was expected because benthic biomass was involved in the estimation of respiration rates. However, it is still useful to examine the full data set in this fashion for descriptive purposes. There were very few occasions (5) when calculated macrofaunal respiration was greater than $4 \text{ g O}_2 \text{ m}^{-2} \text{ day}^{-1}$ which is about the highest total SOC measurement we have found in the bay region (Boynton et al. 1995) suggesting these algorithms are reasonable as first approximations. Additionally, the data plotted in Figure 5a suggests two upward sloping clusters of observations. This results because several different temperature related algorithms were used in making respiration estimates. It may be useful to further refine the temperature component of these calculations but that would probably involve making new laboratory measurements. Finally, there was somewhat reduced macrofaunal respiration rates estimated at the highest biomass levels and this results from the fact that larger organisms (with lower weight specific respiration rates) made up a good deal of the biomass under these circumstances.

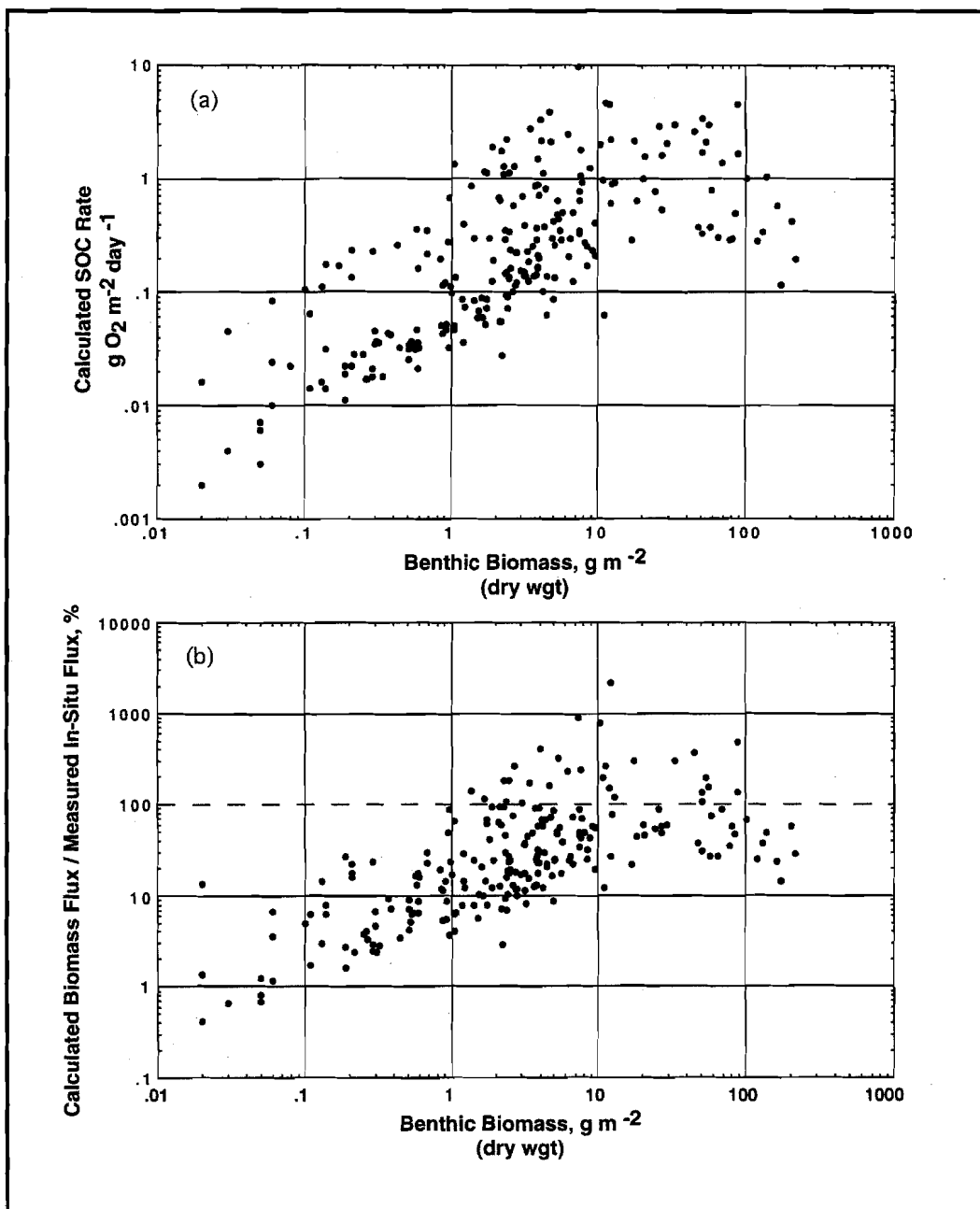


Figure 5. Two scatter plots indicating relationships between benthic infaunal biomass observed in sediment cores and (a) calculated SOC flux associated with benthic infauna and (b) the calculated SOC flux expressed as a percent of the total, measured in-site SOC flux. All data (251 cores) were used in these plots.

Calculated Rates of Ammonium Excretion by Benthic Macroinvertebrates

General Characteristics: A frequency of occurrence plot of calculated benthic macroinvertebrate ammonium excretion expressed as percentage categories of total sediment ammonium flux is provided in Figure 6. The most common contribution of macrofaunal ammonium excretion to total sediment ammonium flux is in the range of 0 to 10% and this occurred in about 29% of the samples analyzed. Approximately 54% of samples had macrofaunal ammonium excretion as less than 30% of total sediment ammonium flux. Only 16% of all samples had macrofaunal ammonium excretion as greater than 30% of total sediment ammonium flux (but less than 100%). Based on the calculated macroinvertebrate ammonium excretion rates, 37 samples (18% of total) had rates which exceeded the total observed sediment ammonium flux.

There also appears to be general agreement between the distribution of these excretion rates (expressed as % of total sediment ammonium flux) and biomass data as expected because estimation of macrofaunal ammonium excretion is directly proportional to biomass (Figures 2 and 3). In this sampling, macrofauna contributed a small to modest amount to total sediment ammonium.

The fact that so few (18%) of the calculated macrofaunal ammonium excretion rates were >100% of measured total sediment ammonium flux is comforting and again suggests that reasonable algorithms were used in developing these first approximations of the relative contribution of macrofauna to total sediment ammonium excretion. The fact that some calculations yielded macrofaunal ammonium excretion rates of >100% of the measured total is not surprising in view of the fact that (1) temperatures in-situ and those used in algorithms were not exactly the same and, in the case of ammonium excretion, only one temperature was used; (2) animal species sampled in the field were not generally the same as those used to develop the ammonium excretion algorithms because data for those species did not exist and (3) nothing was known about the condition of macrofaunal species at time of measurement; they may have been healthy or stressed due to poor DO or some other environmental conditions that would alter excretion rates from those observed under laboratory conditions. Finally, there is always room for suspicion about the realism of laboratory-based estimates of rates such as ammonium excretion. Overall, this analysis indicates a small to modest contribution by macrofauna to total sediment ammonium flux in most samples (0-20%) and a modest to large contribution (50-100%) in a small number of samples where macrofaunal biomass was relatively large ($> 10 \text{ g m}^{-2}$; shell-free dry weight).

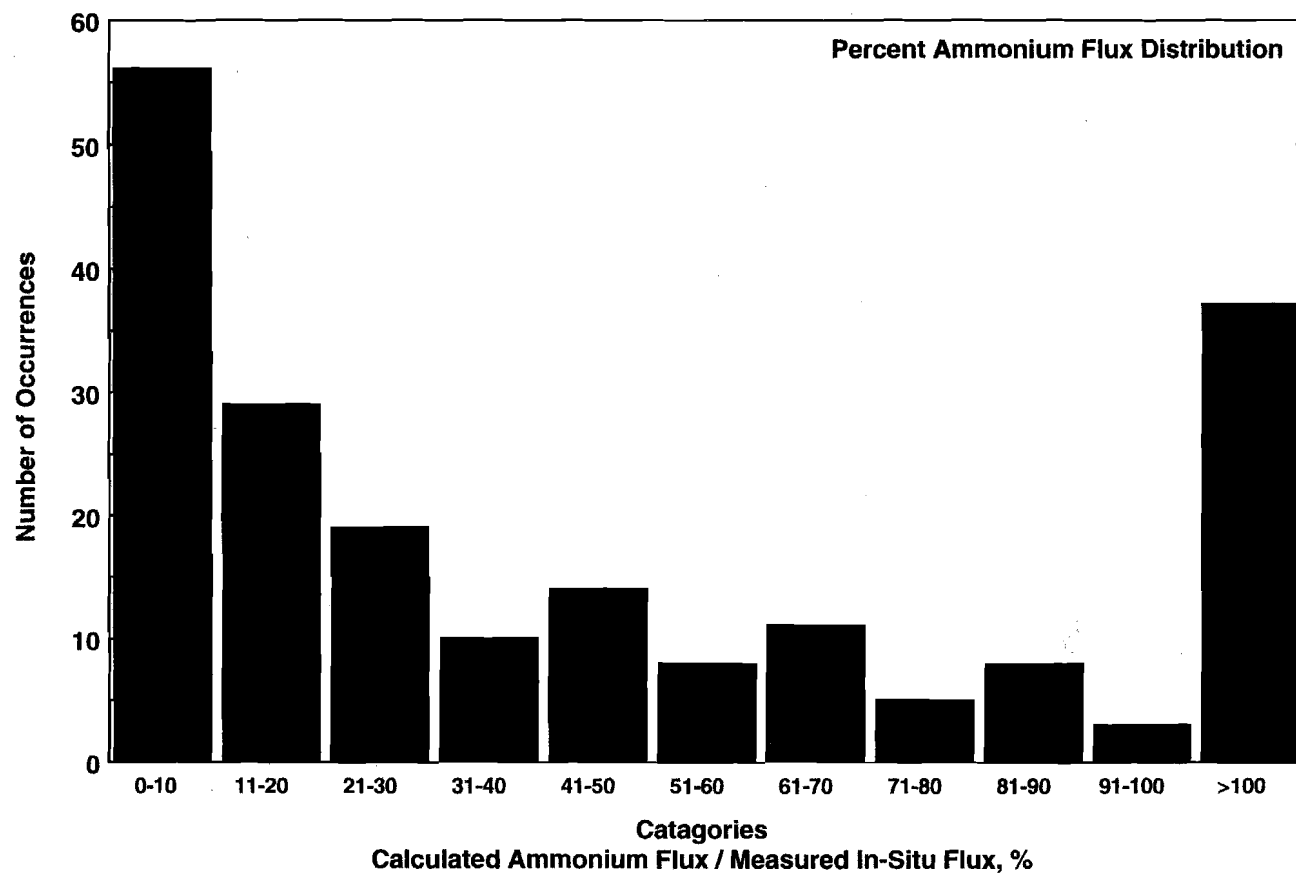


Figure 6. A simple bar graph indicating the distribution of percent of total in-situ ammonium flux attributable to benthic infauna. The total number of samples was 251.

Relationships to Benthic Macroinvertebrate Biomass: Calculated macrofaunal excretion rates and these rates expressed as a percentage of total sediment ammonium flux were plotted as a function of benthic macrofaunal biomass (g m^{-2} , shell-free dry weight) and are shown in Figure 7. The positive general shape of these scattergrams was expected because benthic biomass was involved in the estimation of excretion rates. However, it is still useful to examine the full data set in this fashion for descriptive purposes. The small degree of scatter in the data shown in Figure 7a (compared to data shown in Figure 5a) largely resulted because only one temperature was used in estimating macrofaunal ammonium releases. It may be useful to further refine the temperature component of these calculations but that would probably involve making new laboratory measurements. There was only one occasion when calculated macrofaunal excretion was greater than $500 \mu\text{mol N m}^{-2} \text{hr}^{-1}$ which would be considered a high value for total sediment ammonium release in the bay region (Boynton et al. 1995). The general range of calculated rates suggests these algorithms are reasonable as first approximations. There were many biomass observations in the range of $1 - 10 \text{ g m}^{-2}$ (shell-free dry weight; Figure 7a) which resulted in calculated macrofaunal excretion rates between 10 and $100 \mu\text{mol N m}^{-2} \text{hr}^{-1}$. Rates of this magnitude are a small to modest component of sediment ammonium releases normally observed in the bay region.

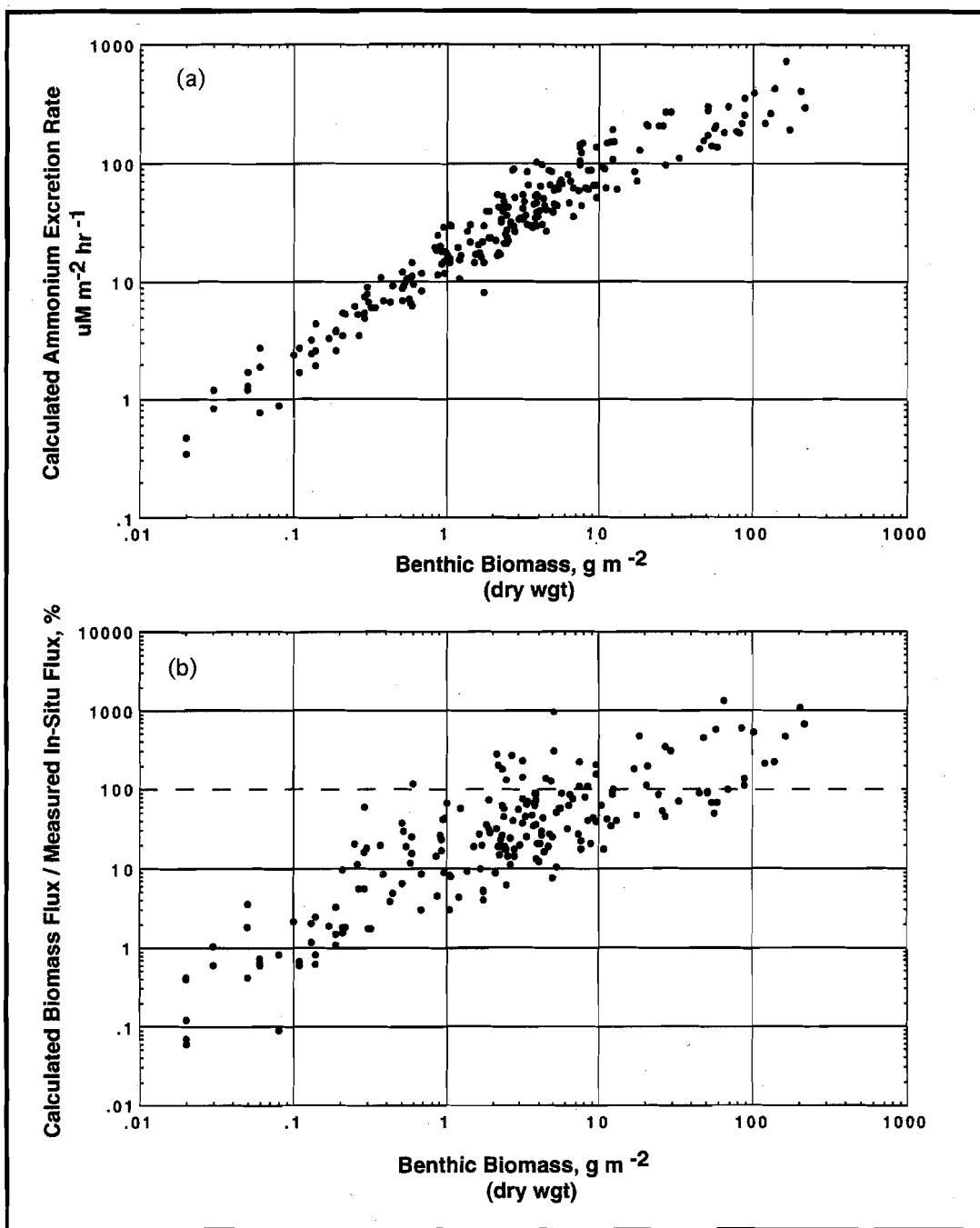


Figure 7. Two scatter plots indicating relationships between benthic infaunal biomass observed in sediment cores and (a) calculated ammonium flux associated with benthic infauna and (b) the calculated ammonium flux expressed as a percent of the total, measured in-site ammonium flux. All data (251 cores) were used in these plots.

SUMMARY AND CONCLUSIONS

- The sediments of Chesapeake Bay and other shallow estuarine ecosystems are an important location in determining the fate of nutrients entering the estuary and a sink for dissolved.
- Because of the strong impact sediments have on water quality, the role of sediments in storing, transforming, and releasing nutrients has been incorporated into the Chesapeake Bay water quality model. Other steps are being taken to further the model's performance, and one of these involves incorporation of a simplified benthic food web.
- The purpose of this study is to estimate the portion of sediment oxygen consumption (SOC) and sediment ammonium (NH_4^+) release directly attributable to benthic invertebrates via the respiratory use of oxygen and catabolic release of ammonium.
- Intact sediment samples were collected at 8 locations from August 1985 through November 1988. Four stations were located in the mainstem of Chesapeake Bay, two in the Patuxent River and two in the Potomac. At each station measurements were made, using intact sediment cores, to estimate net sediment-water exchanges of ammonium and dissolved oxygen. In addition, macrobenthic invertebrates were removed from each core, identified, counted and weighed. A total of 251 cores were selected for examination in this study.
- No direct measurements of macroinvertebrate respiration or ammonium excretion were available for the stations sampled. However, since the macroinvertebrates recovered from each core were weighed and identified and the relationship between body size (weight) and respiration and excretion is reasonably well known, it was possible to calculate these rates for each core and compare these values to the total sediment flux of dissolved oxygen and ammonium.
- The most common biomass associated with sediment cores fell in the range of 1.0 to 9.9 g m^{-1} . Approximately 34% of all cores had macroinvertebrate biomasses of less than 1.0 g m^{-2} , a very low value for a rich estuary. Only 14% of the samples had biomass estimates in the range of 10 to 99.9 g m^{-2} and only 4 % were greater than 100 g m^{-2} . The latter two categories, representing 18% of the total number of samples analyzed (45 cores), had benthic macroinvertebrate biomasses which were moderate to large and expected to have a substantial influence on oxygen consumption rates, ammonium excretion rates and other ecological functions.

- At the deeper stations which are exposed to seasonal hypoxia or anoxia benthic macroinvertebrate species were generally of limited abundance; most of the time >90% of the biomass was accounted for by one or two species, usually small polychaetes such as *Paraprionospio pinnata* and *Strablospio benedicti*. At two of the tributary stations there was higher diversity in the species assemblage; generally two or three species of amphipods (*Leptocheirus plumulosus*), polychaetes (*Paraprionospio pinnata* and *Strablospio benedicti*), gastropods (*Acteocina canaliculata*) or bivalves (*Macoma balthica* and *Mulinia lateralis*) made up > 90% of the biomass. At the remaining two sites (upper Patuxent and upper Chesapeake Bay mainstem) benthic species diversity was even greater; three to six species (e.g. amphipod *Leptocheirus plumulosus*; isopod *Cyathura polita*) were needed to account for >90% of the biomass and bivalves (*Macoma balthica*) were often the dominant species.
- The most common contribution of macrofaunal respiration to total SOC is in the range of 0 to 10% and this occurred in about 31% of the samples analyzed. Approximately 63% of samples had macrofaunal respiration less than 30% of total SOC. Only 26% of all samples had macrofaunal respiration greater than 30% of total SOC.
- The most common contribution of macrofaunal ammonium excretion to total sediment ammonium flux was in the range of 0 to 10% and this occurred in about 29% of the samples analyzed. Approximately 54% of samples had macrofaunal ammonium excretion rates less than 30% of total sediment ammonium flux. Only 16% of all samples had macrofaunal ammonium excretion rates greater than 30% of total sediment ammonium flux. Rates of this magnitude are a small to modest component of sediment ammonium releases normally observed in the bay region.

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